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SALT MARSH RESTORATION

A GUIDEBOOK FOR SOUTHERN CALIFORNIA

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by Joy B. Zedler

A California Sea Grant College Program Publication

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The California Sea Grant College Program is a statewide, multiuniversity program of marine research, advisory services, and education activities, administered by the University of California Institute of Marine Resources. Through the research it sponsors, Sea Grant contributes to the growing body of knowledge about our coastal and oceanic resources and helps solve contemporary problems in the marine sphere. Through its Marine Advisory Program, Sea Grant transfers information and technology developed in its research efforts to a wide community of users in California, the Pacific region, and the nation. Sea Grant also supports a range of educational programs for students, teachers, and the general public to promote the wide use of our coastal and oceanic resources by this and future generations.

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California Sea Grant Report No. T-CSGCP-009

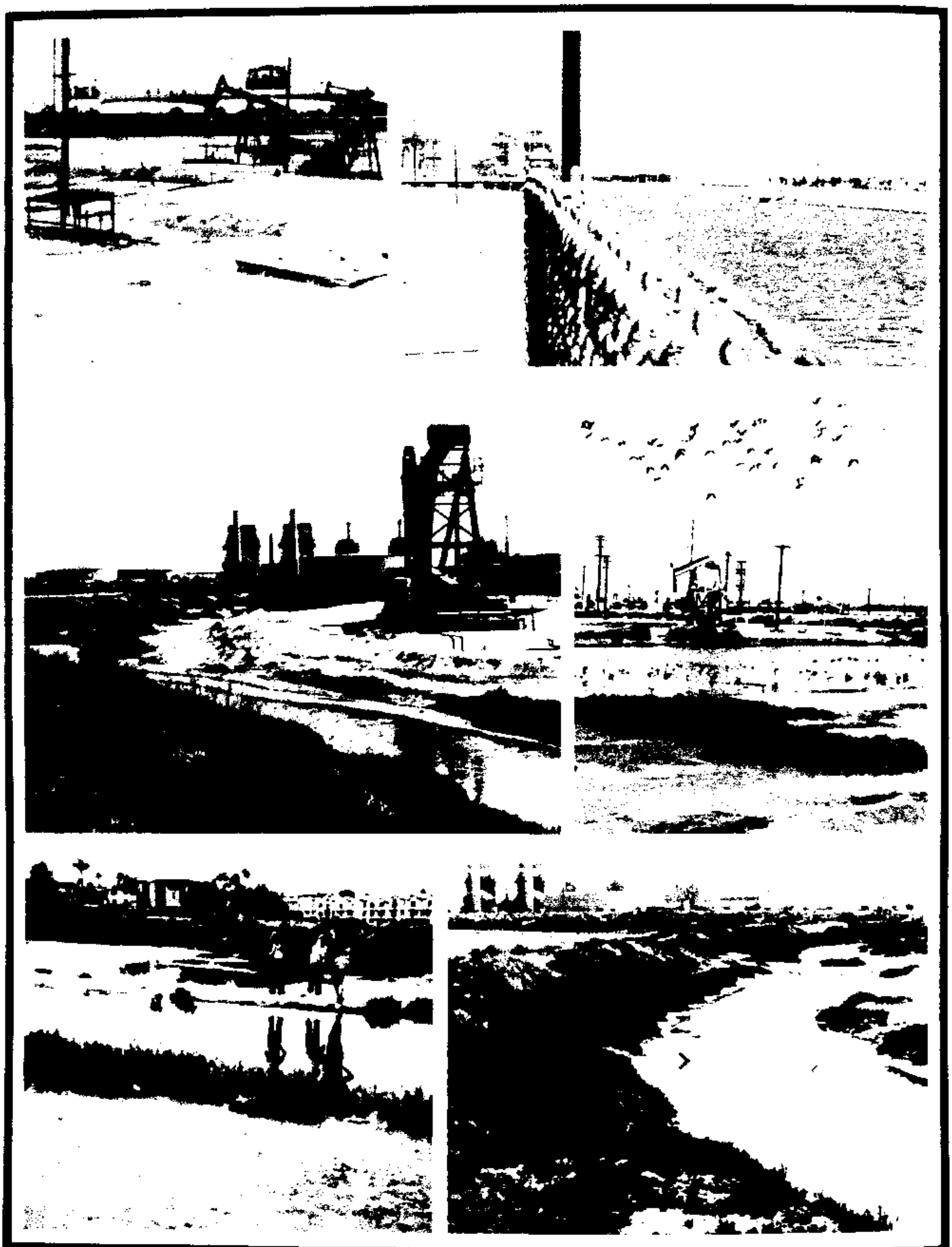

Figure 1. Disturbance is a common feature of southern California salt marshes.

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PREFACE

Researchers have long suspected that extreme dryness, intermittent runoff, catastrophic flooding, and human-induced degradation all affect California's coastal wetlands. Until recently, the extent to which these changes affect ecosystems was not well understood.

The California Sea Grant College Program has played an important role in supporting research to provide a better understanding of how coastal wetlands have been altered by human activities in particular. In 1976, studies of selected wetlands were initiated under Sea Grant support. The effects of reduced tidal flushing were identified, the intricacies of vegetation and salinity relationships were uncovered, and the interactions between the salt marsh canopy and its underlying algal mats were examined and documented. As a result of these early research projects, a general understanding of the salt marsh ecosystem and the responses of wetlands to human disturbances began to develop.

Sea Grant then sponsored research to understand how to reserve the course of wetland degradation by restoring degraded wetlands to predisturbance conditions, insofar as those conditions were known. The work began with studies of cordgrass vegetation and grew to include all wetland habitats as demand for information and involvement in coastal restoration increased. To meet the needs of government agencies, land owners, and wetland consultants, Dr. Joy Zedler, California Sea Grant's coastal resources specialist, recorded many of the recommendations that grew out of her research. Her restoration guidelines were circulated in draft form among a wide variety of managers, consultants, and developers, who in turn gave helpful advice for improvement. Through scientific research and direct involvement in restoration planning, as well as interactions with many users, this guidebook evolved.

Sea Grant is pleased to make available the results of its wetland restoration research and planning. As new problems confront wetlands managers, Sea Grant will continue to support research efforts to solve them. We encourage your comments and suggestions toward those goals.

James J. Sullivan
Program Manager
California Sea Grant College Program

The influence of man along California's coastline has a long history, and the most extensive modifications appear to have occurred in the shallow-water habitats associated with embayments. As a result, all of southern California's salt marshes have been disturbed, and naturally functioning communities of plants and animals are in danger of extinction. The list of disturbances includes artificial filling, off-road vehicle use, trampling, artificial drainage, altered stream discharge, reduced tidal flow, dikes, and dredging. The effects of these modifications are not thoroughly understood, but selected, large-scale changes, such as reduction of tidal flushing, augmented sedimentation, and altered flooding regimes have been studied in southern California. The changes are often substantial and long lasting.

This guidebook seeks to help reverse the process of salt marsh destruction and degradation. It gives advice on how to restore and enhance disturbed marshes. This information developed during six years of intensive study of Tijuana Estuary (a relatively undisturbed system), comparative studies in Los Penasquitos Lagoon and the San Diego River Marsh, and interaction with a broad range of management agencies. The research work has been funded largely by the California Sea Grant College Program with additional support from the U.S. Fish and Wildlife Services, the U.S. Navy, and the Unified Port of San Diego.

Who is this written for?

. . . all those concerned with restoring coastal salt marshes.

Wetland restoration involves many "players." Identifying you, the users of this guidebook, is facilitated by following the process of planning and implementing a wetland restoration project. While there are many ways that restoration projects become initiated – arising from land use conflicts; arising from concerns of environmentalists; arising from plans to develop part of a wetland – a scenario such as the following is one example.

DEFINITIONS OF TERMS USED IN THIS GUIDEBOOK:

MANAGEMENT TERMS:

RESTORATION: Implies returning a system to its predisturbance condition, but because this is usually impossible, the term is expanded to mean creating habitat types which were formerly more abundant. The actual re-creation of predisturbance conditions becomes impossible for three reasons given on page 7 and in Zedler, Josselyn, and Onuf (1982).

ENHANCEMENT: Increasing the value or attractiveness to wildlife; improving upon existing conditions. In the context of this guidebook, enhancement involves improving the area or condition of existing habitats or communities, rather than creating a system de novo. Elsewhere, the terms enhancement and restoration are used interchangeably. It seems useful to separate their usage in managing coastal wetlands, as in this example: Within a given acreage or project area, existing habitat types, such as pickleweed marshes, would be "enhanced" — that is, either improved *in condition* by improving tidal flushing or *in amount* by expanding the area of tidal inundation. Highly degraded areas would be "restored" to some new condition deemed desirable by the management agencies. The overall project would be termed a restoration project.

DEGRADED: The California Dept. of Fish and Game has adopted the following definition:

> *"A wetland which has been altered by man through impairment of some physical property and in which the alteration has resulted in a reduction of biological complexity in terms of species diversity of wetland-associated species which previously existed in the wetland areas."*
>
> (Department of Fish and Game, 1981, "Determination of the status of the Bolsa Chica Wetlands").

ECOLOGICAL CLASSIFICATION OF HABITATS:

SALINE CONDITIONS: Soils or waters that are high in salt content, that is, more than 0.5 parts per thousand (= 0.05% salinity). Usually sodium chloride (NaCl) is the predominant salt, but some areas have high concentrations of sulfates, carbonates, and bicarbonates as well. Habitats are commonly subdivided on the basis of total salt content. The classification scheme of Cowardin *et al.* (1979) is used on the following page.

Landowner: suggests plan for development within a wetland plus mitigation involving restoration.

Hydrologists and engineers: advise on design feasibilities

Landscape architects: draw up possible configurations.

California State Coastal Conservancy: assists with planning; may assist in funding, in accordance with Coastal Act provision; may purchase part of the land

Scientists: advise agencies, advise consultants

Attorneys: advise on legality of plans and decisions.

Consulting firms: advise Conservancy; advise landowner.

Municipal Planning Dept.: incorporates plans into Land Use Plan.

Citizen groups: react to plans, help improve plans

California Coastal Commission: evaluates plan, makes decision on consistency with Coastal Act.

Government agencies: are approached for the necessary permits – this may include California Department of Fish & Game, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency; Regional Water Quality Boards, etc.

In an actual planning process, these groups would interact in a variety of interchanges, not necessarily in the order given here. Implementation then involves many of the same players – landowner, consulting groups, and volunteer citizens who may take a very active role in on-site restoration.

Table 1. Salinity Classification.

Conditions	Salinity (ppt)	Salinity (%)	Appropriate specific conductance (milliMhos @ 25° C)
Fresh	under 0.5	under 0.05	under 0.8
Brackish	0.5-30	0.05-3	0.8-45
Euhaline or saline	30-40	3-4	45-60
Hyperhaline or hypersaline	over 40	over 4	over 60

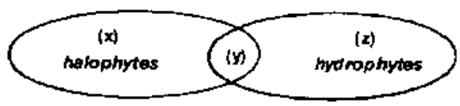
SALT MARSH: A community of organisms dominated by plants that are tolerant of wet, saline soils; generally found in low-lying coastal habitats which are periodically wet and usually saline to hypersaline. The ecological features of southern California salt marshes are described in detail in the Community Profile.

The term salt marsh summarizes the *saline conditions* of the habitat as well as the *emergent vegetation* which dominates it. Plants which grow in salt marshes are thus tolerant of two conditions: saline and wet. Saline conditions sometimes occur in the absence of wet soils, and wet conditions often occur in the absence of salinity. The terminology which has developed to describe these situations is presented in the following, simple model:

The salt marsh occurs in the zone of overlap (y) while habitats such as dunes, coastal cliffs, and salt deserts would appear in the saline, non-wet habitats (x); and freshwater marshes, ponds, streams and lakes would appear in the wet, non-saline habitats (z).

Conditions: Saline Wet

Descriptive term for resident plants:



WETLAND: A term defined by California's Coastal Act (Section 30121) as follows:

> "*Wetland means lands within the coastal zone which may be covered periodically or permanently with shallow water.*"

As used here, the wetland is considered to include all the periodically wet habitats, with water provided from tides, seepage, rain, or stream discharge. A gradient of "wetness" occurs from one habitat to the next, so that it is difficult to identify the boundaries of each exactly, but the following types of habitats and communities are usually distinguishable:

Shallow to deep channels	Salt marsh
Tidal creeks	Salt flats
Eelgrass beds	Alkali flats
Intertidal sand and mudflats	Transition to upland

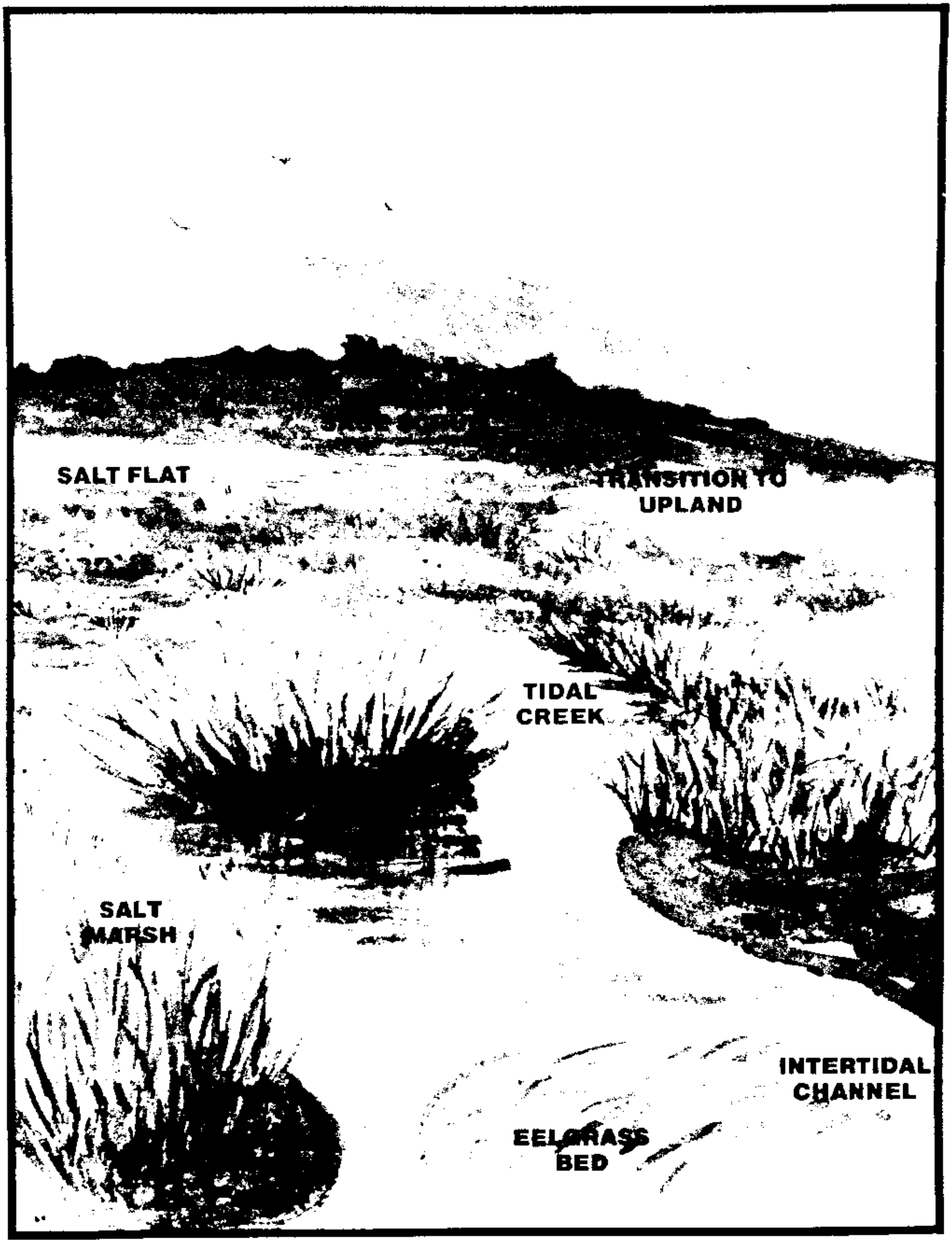


Figure 2. Habitat types in a coastal wetland.

ECOLOGICAL CLASSIFICATION OF PLANTS:

GLYCOPHYTE: A plant that cannot tolerate saline conditions.

HALOPHYTE: Plants which tolerate *saline conditions.* Salts pose a two-fold problem for most plants — the sodium ions are toxic to plant metabolism and salty water is difficult for plants to absorb to meet their water requirement. Relatively few species of plants are adapted to saline conditions, the mechanisms by which halophytes do so are treated in detail by Waisel (1972).

> *"Controversial data exist regarding the question of whether halophytes require saline conditions for their existence and vigorous growth or merely tolerate them . . . . Only a few species seem to require salts obligatorily. Nevertheless, even though most halophytic species are also capable of growing in salt-free media, those plants are usually limited in their distribution to salines."*
>
> (Waisel 1972)

HYDROPHYTE: Plants which tolerate wet conditions. Wet soils are prone to develop anaerobic (low oxygen concentration) conditions because oxygen has low solubility in water, and because microbial activity (and hence oxygen consumption) is generally high under moist conditions. Plants which tolerate wet or periodically wet conditions have aerenchyma (plant tissue high in air spaces) in their stems and roots to allow rapid diffusion of oxygen from the photosynthesizing (oxygen-producing) tissues above ground to their below-ground parts. Hydrophytes are often classified according to their growth form which in turn relates to the usual water depth:

DESCRIPTIVE TERM		EXAMPLE
Free-floating (roots in water)		**Water hyacinth; duck weed (none occur in salt marshes)**
Submergent (roots in soil, leaves and stems in water)		**Ditch grass = widgeon grass (*Ruppia maritima*)**
Emergent (roots in soil, stems and/or leaves above water)		**Most marsh plants, e.g. the halophytes cordgrass (*Spartina foliosa*) and pickleweed (*Salicornia virginica*), and the freshwater cattails (*Typha* spp.).**

For more detailed information

on the region's salt marshes, and especially for descriptions of naturally functioning salt marsh communities, refer to the following monograph and references cited therein:

Zedler, Joy B. The Ecology of Southern California Coastal Salt Marshes: A Community Profile. 1982. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C. FWS/OBS-81-54. 110 pp.

This book is available free of charge from:

Information Transfer Specialist
USFWS/NCET, NASA-Computer Complex
1010 Gause Blvd.
Slidell, LA 70458

For a general progress report on restoration, refer to the Proceedings of the February 1982 "Workshop on Wetland Restoration and Enhancement in California" edited by Michael Josselyn and available from:

Tiburon Laboratory
P.O. Box 855
Tiburon, CA 94920

and

California Sea Grant College Program
University of California, San Diego
A-032
La Jolla, CA 92093

For a detailed discussion of Coastal Act policies that pertain to wetlands, refer to:

California Coastal Commission. 1981. Statewide Interpretive Guidelines for Wetlands and Other Environmentally Sensitive Habitat Areas. Available from: Calif. Coastal Commission, 631 Howard St., 4th Floor, San Francisco, CA 94105

For information on wetland restoration elsewhere in North America, refer to Brown et al. 1979, Garbisch 1977, Knutson 1977, Lewis 1982, and Pomeroy et al. 1981a and 1981b (listed in the Bibliography).

THE NEED FOR SCIENTIFIC APPROACHES TO WETLAND RESTORATION

Wetland restoration is still in the experimental phase. Several projects have begun in coastal southern California, but there are still unknowns about how to achieve project objectives. Interaction with wetland hydrologists and scientists early in the process is recommended to improve chances of project success and to design projects so that future restoration efforts will be even better (Zedler, Josselyn, and Onuf 1982).

Who are the scientists?

Wetland scientists are people who actively use scientific methods to study wetland organisms and habitats. They include ecologists, botanists, zoologists, soil scientists, and hydrologists who develop and test ideas about wetland structure and functioning. Some are employed by universities and governmental agencies, others work as consultants.

How can a scientist help?

. . . In a variety of ways throughout the process:

1) Setting project objectives – field biologists can help to determine how a specific site can fit into the overall restoration plans for a region. Persons familiar with the site can provide valuable information on the interaction of the site with other wetlands through their knowledge of migrating species and local movements of animals and dispersal patterns of plants.

2) Assessing the site and developing the site plan – field ecologists can identify areas of special ecological significance which should be enhanced or salvaged. They can also identify potential problems important to the site-planning process, such as problems of water supply, drainage, salinity, buffer requirements, wildlife access, etc.

Scientific input is especially important at this stage because of the need to assess the site's potential for enhancement or restoration. Because so little is known about marsh restoration, each site has potential for advancing our knowledge. Because many of the questions on how to plan the restoration lack easy answers, a wetland scientist can give advice on how to design the restoration in order to provide the necessary information. In many cases, it will be necessary to do on-site experiments (cf. Zedler 1983) to determine requirements such as "How deep must pond water be to prevent (or allow) cattails to develop? How steep can intertidal slopes be and still allow salt marsh vegetation to develop? How much emergent vegetation can there be and still allow mosquitofish to control mosquito populations?

To illustrate how the scientific experiments (with controls and regulation) can be incorporated into a restoration plan, consider the examples A-B in figure 3.

A) We know that revegetation is slow on compacted soils (abandoned roadways and paths), but it's not clear how much soil tilling is required to encourage reestablishment of marsh plants. For the State Coastal Conservancy's restoration project at a portion of Tijuana Estuary, we recommended setting up treatments that would utilize hand tilling and mechanical tilling for comparison with control areas where no modification was planned. In addition, we suggested investigating the possibility that burrowing invertebrates might be able to aerate soils and initiate a small project to study and evaluate their subterranean activities.

B) We know that the endangered plant, salt marsh bird's beak (*Cordylanthus maritimus* ssp. *maritimus*) has been eliminated from some coastal wetlands, and artificial establishment in wetlands within its historical distributional range is a stated goal of the U.S. Fish and Wildlife Service's Draft Recovery Plan for the species (US FWS 1983). Dunn (in prep.) has found that the plant grows well in areas of low cover (little competing vegetation) and that drought provides a stress and appears to be the cause of much mortality. However, it is not clear what clearing and watering regimes are desirable or necessary to ensure successful germination, growth, and reproduction of bird's beak. Replicated treatments such as in figure 3B are needed.

3) Carrying out site plans. The construction should be phased to allow for salvaging vegetation and substrates of ecological value. Later they can be moved to desired sites. Field biologists should work on-site with the construction crew. Topographic changes that are being made to facilitate experimentation should be supervised by the scientist who plans them. Initial plantings should be done in experimental fashion, especially for species whose ecological requirements are poorly known.

4) Monitoring the site. In many cases it will be necessary to mitigate the destruction of degraded habitat by providing improved wetland habitat. Improvements should precede destruction. Assessment of the improvements will require monitoring and input from wetland ecologists.

5) Assessing the project's success: recommending improvements for future projects. Does the restored wetland resemble the desired mixture of coastal communities? Comparison with attributes of more natural wetland communities (i.e., existing data bases or concurrent sampling of nearby less-disturbed systems) will be required. Reference to unpublished data (and hence involvement of scientists) will probably be necessary.

What are the mutual advantages of scientific participation?

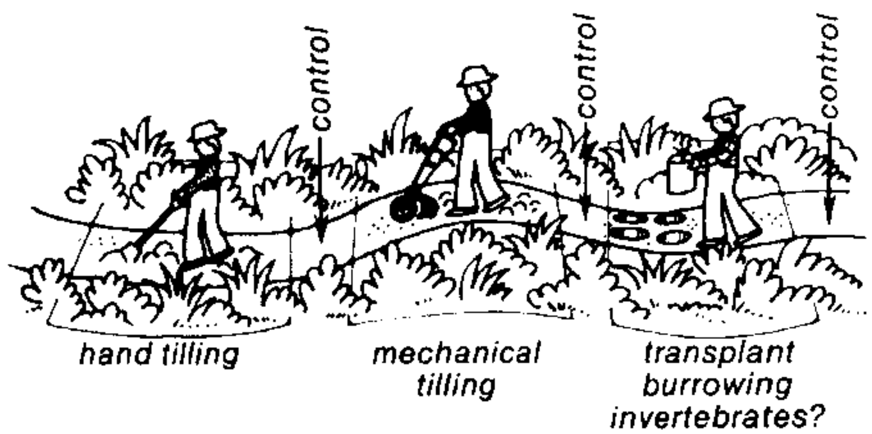
Science and management are potentially very compatible, and involvement of the scientific community in wetland restoration should be viewed as an asset, rather than a threat to the project's approval and completion (Metz and Zedler 1983).

The project will benefit from having available the latest knowledge of wetland species and habitats, which can be applied in the above restoration phases. Furthermore, the project may entice the involvement of students or faculty whose research interests overlap with project needs. Some of the information may be developed concurrently with ongoing funded work in a mutually beneficial manner. If so, the scientific community will benefit by having access to sites where field experimentation can be done and where organisms can be observed expanding into newly constructed sites. Understanding of plant and animal dynamics would thereby be fostered. The scientists and their funding agencies will have the satisfaction of seeing their research results put to practical use . . a factor which is becoming more important as competition for research funds increases.

Are there any drawbacks?

Few benefits come without costs. Fostering the science of ecological management may not expedite a given restoration project. For example, constructing a range of slopes to determine the optimal salt marsh habitat may be more expensive than a single grading. However, failure to bring science into the program may also be costly – if the single grading fails to support transplanted vegetation or does not allow natural colonization by salt marsh species. Until this guidebook can be revised to provide fail-safe methods for restoring marshes, science is an essential part of wetland restoration.

A. Establish replicate plots using a variety of tilling methods to determine the best procedures for aerating compacted soils.



B. Add seeds with appropriate replicated treatments to determine what's necessary for successful establishment of salt marsh bird's beak (an annual plant).

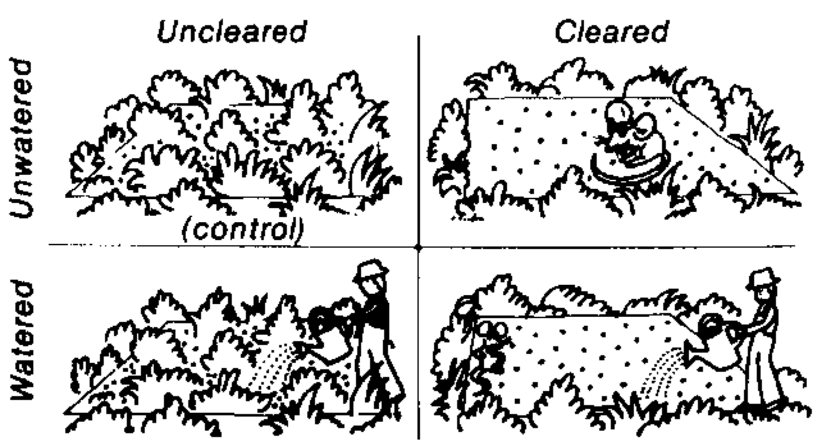


Figure 3. Experiments to determine what marsh restoration techniques are required.

THE GOALS IN RESTORING AND ENHANCING SALT MARSHES AND COASTAL WETLANDS

A variety of restoration goals have been expressed in recent years, including replacing what's been lost, managing for endangered species, increasing "diversity," maintaining "biological productivity," and treating wastewater. Just what each of these means and what problems are involved in attaining the goals are topics for further analysis. The discussion which follows points out many difficulties both in setting and achieving these types of goals. But, after considering the various possibilities, some recommendations (next section) can be made.

1. Replacing what's been lost

The general goal behind the "restoration movement" is to reverse the damage that has been done to coastal ecosystems over the last century. Yet, for several reasons, this goal is difficult to achieve. First of all, we are unsure of the character of coastal wetlands as they existed a century or more ago. Old maps tell us something of the former wetland acreage, but little of the community composition. It is clear that we have lost thousands of acres of wetland habitat, but unclear what fraction of that habitat was high marsh, low marsh, salt flat, intertidal flat, brackish or freshwater marsh, tidal creeks, or deeper channels, nor do we have records of what these communities were like. The early monograph of Edith Purer (1942) describes San Diego County's salt marsh resources prior to the postwar development boom, but even then, many roads had been built across wetlands, dikes were in place, and filling was commonly encouraged to "reclaim" wetlands. More recent assessments (e.g., California Dept. of Fish and Game Resource Inventory series) have attempted to assess the changes that have occurred within our salt marsh communities, but only general statements are possible.

Second, there are many disturbances that are irreversible, especially the manipulation of watershed hydrology (e.g., dams that alter flow rates and periods of discharge and irrigation using imported water). Yet watershed hydrology is extremely important in determining the character of coastal wetlands. Restoration efforts must take into consideration the qualities of the adjacent and upstream land uses.

Finally, wetland ecosystems are highly dynamic. Natural catastrophic events, such as flooding, can change the configuration of a salt marsh by eroding or adding sediments, and the freshwater itself can enhance or reduce growth of wetland organisms. If we selected a point in time to use as a goal for wetland restoration (e.g., a century ago) it would be an arbitrary decision.

"Replacing what's lost" thus becomes an attempt to make our more disturbed salt marshes resemble our less disturbed marshes as they have been described in recent years (cf. Zedler 1982a).

2. Increasing habitat for endangered species

Most species come in danger of extinction because their habitat has been destroyed. Hunting of game animals and competition from exotic species are additional threats to native species, but habitat loss seems to be the major factor involved in the decline of three salt marsh species:

> The light-footed clapper rail (*Rallus longirostris levipes*) lives mainly in cordgrass-(*Spartina foliosa*) dominated low marsh; Belding's Savannah sparrow (*Passerculus sandwichensis beldingi*) nests in upper marsh habitats, especially those dominated by pickleweed (*Salicornia virginica*); and the salt marsh bird's beak (*Cordylanthus maritimus* ssp. *maritimus*) is a plant whose distribution is restricted to a narrow elevational range near the upper intertidal limit.

Because these species each occupy different habitats within the salt marsh, it is easy to see that providing habitat for one may further endanger another (Fig. 4). The rail and the bird's beak are both found only in tidally influenced habitats, and reinstating tidal circulation is a frequent recommendation for restoring wetlands. Yet reintroducing tidal action to diked areas may reduce the area dominated by pickleweed* and hence impact the sparrow's habitat. Similarly, dredging channels to create feeding areas for other endangered birds (e.g., the California least tern, *Sterna antillarum browni*, or the brown pelican, *Pelicanus occidentalis*) might usurp habitat for intertidal species.

Creating habitat for a given endangered species must be viewed as part of an overall wetland restoration plan, though if the space is very limited, one species' habitat may take priority over another's. In such a case, the suitability of the site to maintain different types of habitat should be the major determining factor.

In all cases, single-species management would provide more habitat for that species, but it may also involve increasing the quality of the habitat already there. For the rail, Massey and Zembal (1979) have linked high population densities with tall, lush cordgrass, and studies of cordgrass (Zedler, in press) link good plant growth with increased freshwater input. Rail populations might benefit from enhanced cordgrass growth obtained by occasional irrigation. Other factors important for the rail (such as alternative feeding sites during high tide; protection from predators; etc.) are becoming identified, and management for endangered species should be based on the most current information available. The U.S. Fish and Wildlife Recovery Plans and individuals on their Recovery Teams are essential sources. Recovery plans for individual endangered species may be obtained from:

> Fish and Wildlife Reference Service
> Denver Public Library
> 3840 York Street, Unit J
> Denver, Colorado 80205-3536
> Phone 1-800-525-3426 toll free.

*Pickleweed survives tidal inundation, but it may invade lower elevations when tides are eliminated, only to be drowned when tides are restored.

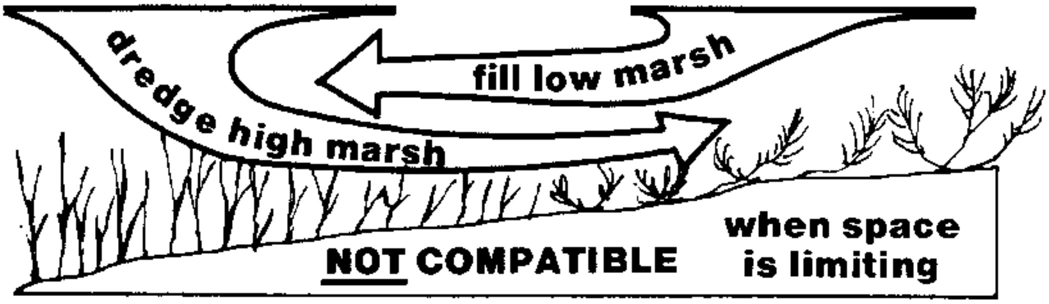
3. Increasing diversity

Diversity has two measures in ecology – the number of different things and their relative abundance. When the "thing" is species, it is preferable to call the first measure "species richness," while indices that also include relative abundance are measures of "species

Managing for one endangered bird may have negative effects on another endangered species, because their habitat needs differ:

To manage for the light-footed clapper rail, increase habitat dominated by cordgrass:

To manage for Belding's Savannah sparrow, increase habitat dominated by pickleweed.



Simultaneously managing for **both** may preclude changing the distributions of the two habitat types, but can still involve improving the quality of each habitat type:

To manage for the light-footed clapper rail, improve the height and density of cordgrass.

(suggested technique: occasional irrigation with freshwater to reduce soil salinities)

To manage for Belding's Savannah sparrow, enhance the growth of pickleweed.

(techniques not yet proven, but occasional watering should work in non-tidal areas; returning tidal action will probably be beneficial)

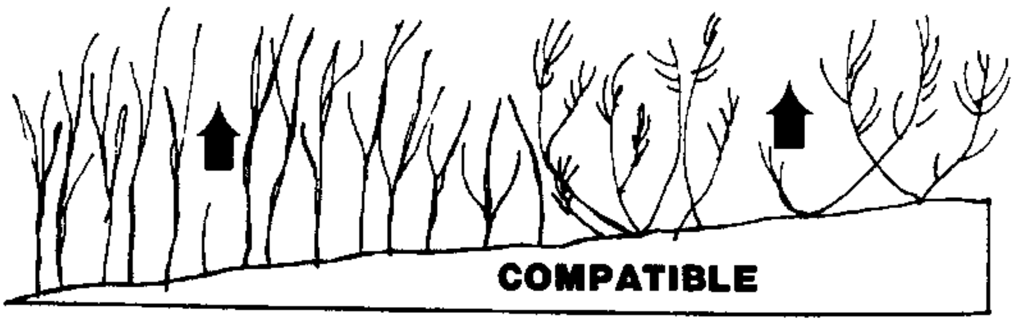


Figure 4. Make sure that restoration techniques are compatible.

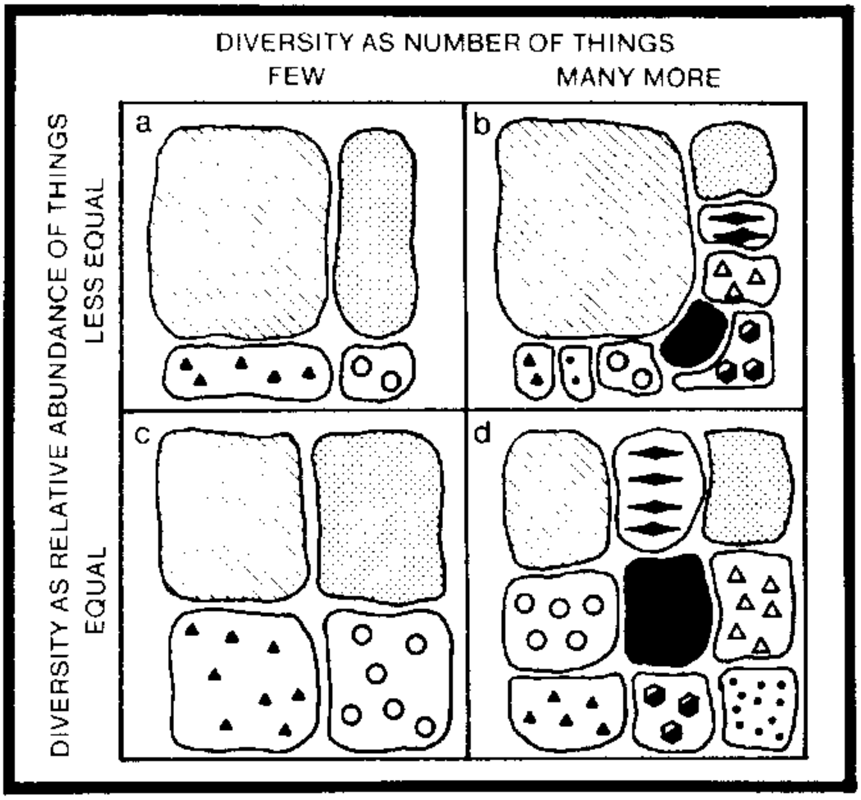


Figure 5. "Diversity" has two meanings.

diversity." When the "thing" is habitat type, there are no separate terms. Yet the distinction is important. It makes a difference if the goal is to increase the number of habitats present on a site or if it is to make the existing habitats more equal in area. A simple model illustrates the difference in the two measures (Fig. 5).

Comparing habitat diversity, "d" is diverse by both measures, having more habitats which are equally abundant, while "a" has a few habitats with one type dominant. Increasing the habitat diversity of "a" might involve adding more habitat types (moving toward "b"), increasing the area of rarer types (moving toward "c") or both (moving toward "d").

4. Maintaining biological productivity and optimum populations

The Coastal Act recognizes that coastal wetlands are biologically productive and requires that productivity be maintained to sustain "optimum populations of marine organisms . . ." (Section 30231). Biological productivity and optimum populations are defined very broadly in the *Statewide Interpretive Guidelines* (California Coastal Commission 1981):

> In general, biological productivity means the amount of organic material produced per unit time. For the purposes of this guideline, the concept of biological productivity also includes the degree to which a particular habitat area is being used by fish and wildlife species. Thus, an area supporting more species of fish and wildlife would be considered more productive than an area supporting fewer species, all other factors (e.g., the amount of vegetative cover, the presence or absence of endangered species, etc.) being equal. (Ibid., p. 23.)
>
> [Optimum populations of marine organisms refer] generally to the maintenance of natural species diversity, abundance, and composition. (Ibid., p. 23.)

Restoration of salt marshes to meet these objectives would provide habitats for the naturally occurring marsh fauna. Fulfilling this fourth goal is thus identical to fulfilling the first goal.

5. Wastewater treatment

Along the Atlantic Coast, experiments using wetlands for the treatment of sewage have shown that salt marshes have potential for absorbing nutrients and purifying waste water (Valiela et al. in press). Most research in this area has dealt with freshwater ecosystems (Dinges 1982). In southern California two experimental projects are investigating the potential of freshwater and brackish plants to purify water (City of San Diego experimental polyculture facility and Santee artificial marshes; Gersberg et al. in press). None of the region's salt marshes is being used to treat sewage, but creation of artificial marshes near salt marshes may be in the future for southern California's coastal cities.

Although it may be possible to use salt marshes for wastewater treatment elsewhere in North America, it is not recommended for southern California. The first reason is the region's small area of salt marsh habitat – any changes brought about by wastewater treatment would substantially alter the resource and conflict with the Coastal Act. Second, it is likely that the effects on southern California's salt marshes would be more dramatic than observed elsewhere (as discussed in Zedler 1982b) because the water to be recycled is imported and freshwater input would be substantially increased.

Nor is it recommended that large volumes of imported water be released upstream of salt marshes, either by using aquaculture treatment systems or artificial marshes, unless it is shown that the augmented stream discharge will not destroy salt marsh habitats. This recommendation does not aim to discourage wastewater recycling. On the contrary, it is essential that precious imported water be reclaimed for reuse. But, it is important that the treatment facility carefully consider the impact of freshwater effluent on downstream ecosystems which are sensitive to changes in salinity. With proper planning, it should be possible to utilize freshwater effluent to benefit wetland restoration, thus turning a management problem into a management solution (Demgen 1981; Zedler 1982b). Restoration projects which have access to wastewater effluent may have the greatest latitude for increasing habitat diversity as well as the greatest potential for vegetation establishment and enhancement. However, the quality and timing of freshwater input which can be allowed without damaging salt marsh communities is not yet known. Using wastewater to aid restoration projects is in the earliest stages of experimentation.

RECOMMENDATIONS FOR DEFINING REGIONAL GOALS AND PROJECT OBJECTIVES

None of the above suggestions is free of planning or implementation difficulties. Yet each has merit and should be considered in determining the course of wetland restorations. The following recommendations are an attempt to incorporate broad goals into the process while reducing the chances of failure by restricting each project to objectives which are most suitable for the site. Each recommendation has been developed after careful consideration by wetland scientists in consultation with the California Coastal Conservancy (cf. Sorensen 1982).

1. Restoration goals should be established for the *region* as a whole.

   Rationale: The natural resources of a region are shared by birds, fish, invertebrates, etc., whose populations (either as young or adults) move from one site to another. A particular site must be viewed as a part of the regional complex for several reasons – it may be too small to support all habitat types desired for the region, and it may be unsuitable for creating all types of habitat. Furthermore, it may be especially well suited to enhancement of one type of habitat, in which case that habitat should be upgraded instead of converted to an alternative habitat at the risk of failure.

2. All of southern California (Point Conception south to Baja California) should be considered a region.

   Rationale: Study of the distributions of wetland and salt marsh species suggests that southern California represents a biogeographic region (Macdonald 1977a,b; Power 1980; Zedler 1982a). Ecological information is insufficient to delineate the southern boundary exactly, but it probably extends to Bahia de San Quintin.

3. Specific site plans should capitalize on the attributes of the site and not necessarily propose to fulfill all regional goals. Wetland habitats of ecological value should be enhanced rather than converted to other wetland communities.

   Rationale: It is easier and less risky to enhance existing wetland habitats than to create new ones artificially. Wetland habitat that is so degraded that enhancement is no longer feasible should be actively converted to other wetland communities, and the type chosen should depend on both the suitability of the site (e.g., access to tidal flushing, availability of freshwater input, etc.) as well as the needs of the region.

4. A single administrative unit should assume responsibility for setting regional priorities for restoration. The unit should set priorities using ecological principles for management of natural ecosystems (e.g., Clark 1977), based on the concept that natural ecosystems are worthy of preservation for their own sake (cf. Ehrenfeld 1976) and based on existing legislation which protects indigenous species (e.g., the Endangered Species Act and the U.S. Fish and Wildlife Endangered Species Recovery Plans).

5. The same administrative unit should update priorities continuously as restoration projects are implemented and as goals are achieved.

   The unit should keep track of a) the objectives that are being planned for each restoration project; b) the extent to which goals are being fulfilled by various restoration projects; and c) the goals that are not being met by ongoing projects. As progress is made toward achieving high priority goals, other goals will take precedence in planning specific projects.

Developing the site plan

The following steps should be taken to develop a comprehensive restoration plan that is consistent with regional goals as well as suitable for the site.

1. The first step will be to examine the areas, with the aid of detailed maps and aerial photos. Because elevation is so critical to salt marsh vegetation, microtopographic contours (0.5 to 1.0 foot) should be mapped. Make certain that the reference datum (mean lower low water, mean sea level, or other) is given on all contour maps. The relationship between MSL and MLLW differs from site to site, but MSL is about 3 feet above MLLW in Tijuana Estuary (National Ocean Survey 1980).

   a. Examine aerial photos, not only of existing conditions, but previous conditions as well. Note areas under water at different times; note configuration of channels. Identify the history of disturbances such as filling, dredging, diking, denudation – see example of Famosa Slough Channel (Fig. 6). Identify areas likely to be highly saline, as evidenced by white salt crusts.

   b. Search for published and unpublished studies of the site. Relevant information may be found in journals, theses and dissertations, government reports, and environmental impact statements.

   c. Visit the site with field ecologists and note different habitats on individual copies of the topo maps. Useful information will be areas where different salt marsh plants occur, relatively undisturbed areas, limits of tidal influence, areas used by birds and other animals, etc. Any field notes on the existing ecological value of the habitat will be important for planning future changes.

   d. Note land use adjacent to the site which may influence habitat quality within the site. Determine the area's potential impact on the restoration by reviewing watershed management plans which will influence runoff and sedimentation. Will flood protection or shoreline maintenance measures impact the site? Locate the nearest wastewater source. Identify quality of ground water if possible.

2. Next, meet with scientists, Coastal Conservancy representatives, and managers from interested agencies to discuss the site's potential in relationship to regional restoration goals.

   a. Review the current regional needs for endangered species habitat; review the region's inventory of various wetland habitat types; identify concurrent restoration planning activities.

   b. Determine the project site's greatest potential on the basis of the field reconnaissance. What are its best ecological features? What habitats could easily be expanded? What constraints are there for establishing new types of habitats? What habitats not present are desirable (according to regional needs)?

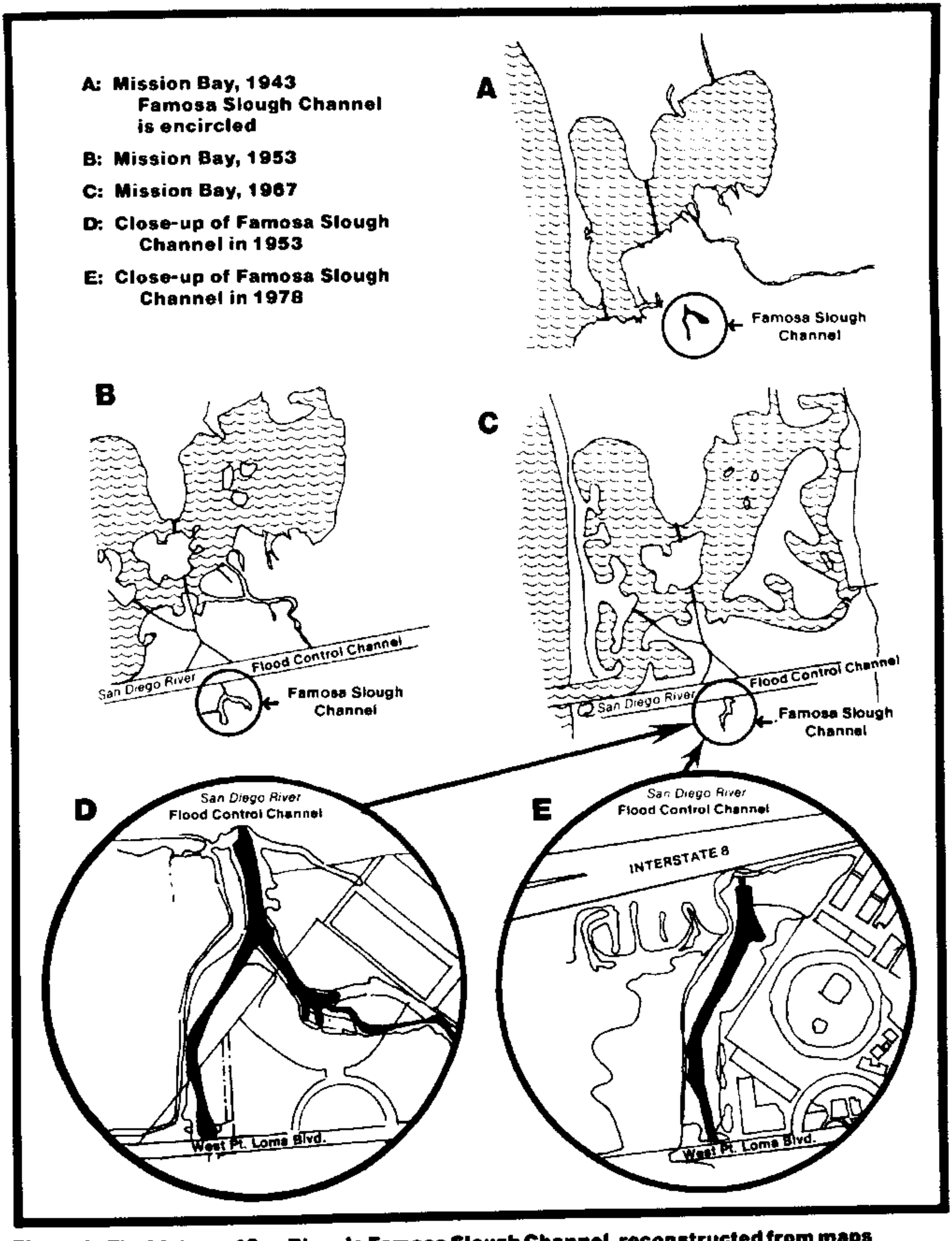
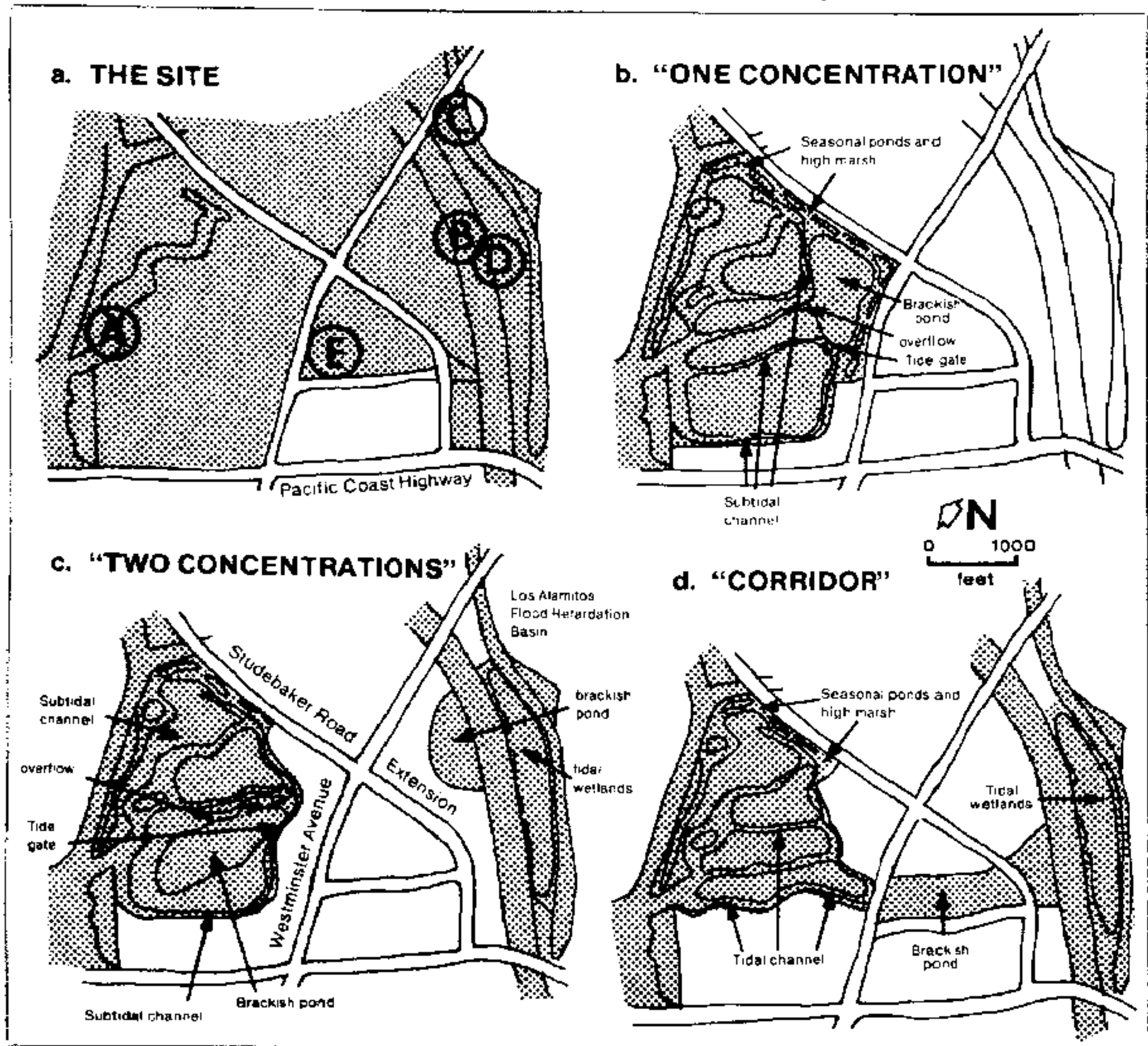


Figure 6. The history of San Diego's Famosa Slough Channel, reconstructed from maps and aerial photos.

Figure 7. Los Cerritos Wetland Restoration Alternatives. (proposed by Sorensen and Associates)



THE EXAMPLE OF LOS CERRITOS WETLAND RESTORATION

Alternative sketch plans for restoring Los Cerritos Wetlands (in Long Beach) were developed by Jens Sorensen and Associates. The restoration planning had the following features which were given at the onset:

- **The site (Figure 7a) included 244 acres. Of this, 129.5 acres were to be restored as wetlands habitat; the remaining acreage would be developed.**
- **Studebaker Road was to be extended through the site.**
- **The site abutted another potential restoration project to the east.**

Study of the area by the Department of Fish and Game and site inspection by scientists indicated that the following ecological assets already existed, although all were disturbed:

A. Intertidal channels, creeks, and marsh (functioning intertidal wetland)

B. San Gabriel River (aquatic habitat)

C. Power plant cooling-water intake (aquatic habitat)

D. Small intertidal channel and marsh connected to river by culvert

E. Artificially-built freshwater pond, heavily used by birds

Following the procedures outlined in the previous section, three alternative sketch plans emerged. Their basic differences and rationale for developing them were:

The "One Concentration" (Fig. 7b) : consolidates all 129.5 acres of restored wetlands into a single unit adjacent to the existing intertidal habitat.
ADVANTAGES: minimal periphery abutting development; large-size wetland; non-saline pond is adjacent to tidal channel (allow flexibility of management).
DISADVANTAGES: existing ecological assets outside the restoration area are destroyed (the small intertidal area "D" and the pond "E"); no marsh habitat would exist adjacent to aquatic habitats "B" and "C".

The "Two Concentrations" (Fig.7c): has two centers of wetland restoration, one adjacent to the large intertidal habitat "A" and another near the smaller intertidal area "D."
ADVANTAGES: both intertidal areas are preserved; marsh habitat is maintained near the aquatic habitats "B" and "C"; non-saline is located adjacent to the intertidal channel (allows flexibility of management).
DISADVANTAGES: the pond "E" is destroyed but replaced by a pond near the larger intertidal area "A"; two smaller restoration sites may be less attractive to wildlife than a single large site.

The "Corridor" plan (Fig. 7d): links the ecological assets "A-E."
ADVANTAGES: none of the recognized assets is destroyed; bird movements between these habitats should be facilitated by the linkage; the restoration site is designed to be continuous with the restoration of wetland habitat to the east.
DISADVANTAGES: this alternative has the greatest periphery abutting development; non-saline ponds are not connected to intertidal channels; two major streets intersect the restoration area.

After the biologists provided suggestions for the restoration design and Sorensen developed their concepts into the above alternative configuration, the project was reviewed by the Coastal Conservancy in conjunction with citizen advisory committees. The alternatives were modified somewhat, and specific engineering sketches were prepared. The nature of the buffer zones surrounding the restoration project became a major issue. Citizen advisors suggested strong desire for viewing access and developers argued for a narrow rather than broad buffer zone. Most of the interface between the development and the restoration project was designated as a 25-foot buffer with a combination of dense vegetation (both shrub and tree), fencing, and a berm next to a deep channel (which was part of the wetland). In contrast, Coastal Commission Guidelines call for a minimum 100-foot buffer.

After months of deliberation, including consideration of economic and feasibility analyses, a plan resembling the original "two concentration" alternative was selected for implementation. Looking back at the process (Sorensen and Gates, 1983), it is clear that biological information was inadequate to develop strong arguments for any one alternative — arguments which would outweigh economic concerns. Still, scientific input made it possible to rule out the least favorable options early on and provided planners with biological advantages and disadvantages from which to consider the more acceptable alternatives.

Los Cerritos wetland's "two concentrations" restoration project will be an experiment to be evaluated over the years as new projects become planned. Unfortunately, without the use of scientific experimentation, using controls and replication (discussed in Zedler 1983), the project will not be able to tell us why it succeeds or fails in its various goals.

c. Although the U.S. Fish and Wildlife Service is developing specific procedures for evaluating habitats (Division of Ecological Services 1980), the approach does not include coastal wetland examples and is not yet being used in southern California. Interaction with agency and other wetland ecologists will therefore be very important.

3. Having reviewed needs and site potentials, lay out specific objectives for the restoration project:

a. List existing habitat types to be increased in area; note methods necessary to accomplish this.

b. List habitat types to be added to the site; note methods necessary to accomplish this.

4. Sketch various site configurations that could achieve the above objectives. An attempt to develop alternative site configurations for Los Cerritos Wetland (see box above) led to several principles that should be considered in future site planning:

a. Plan for habitats that will be self-sustaining to reduce maintenance costs. For example, to create intertidal sand flats place sand along wave-washed rather than quiet shorelines so that it won't be silted in rapidly.

b. Build in flexibility to meet changing habitat needs or to correct habitat restorations that fail. If non- saline ponds are desired, they can be located near tidal channels and separated by tide gates. In the event that such ponds present vector control problems, there is the possibility for periodic drainage or flushing with salt water. Should intertidal habitats become more desirable in the future, the ponds could be converted by opening tide gates.

c. Minimize the boundaries shared with development which will disturb wetland wildlife; that is, reduce the perimeter around the wetland.

d. Create large wetland areas by having the various habitats adjacent to one another.

1) Link together separated wetland habitats to foster wildlife (bird and fish) movements.

2) Consolidate scattered habitats into larger units. These two recommendations may conflict with one another, as was experienced in the planning to restore Los Cerritos wetland.

5. Plan for adequate buffers between the wetland and adjacent developments.

> "A buffer area provides essential open space between the development and environmentally sensitive habitat area. The existence of this open space ensures that the type and scale of development proposed will not significantly degrade the habitat area (as required by Section 30240). Therefore, development allowed in a buffer area is limited to access paths, fences necessary to protect the habitat area, and similar uses which have either beneficial effects or at least no significant adverse effects on the environmentally sensitive habitat area. A buffer area is not itself a part of the environmentally sensitive habitat area, but a "buffer" or "screen" that protects the habitat area from adverse environmental impact caused by the development." (California Coastal Commission 1981, p.21).

Concepts to be considered in designing the buffer zone are discussed following point number 8.

6. Evaluate the alternative sketch plans with the help of scientists and resource managers. Develop a list of advantages and disadvantages from the ecological perspective. Review the configurations in relationship to surrounding land uses in order to assess compatibility. Rank the sketch plans and proceed with specific landscape design for the preferred concept.

7. Plan the details of vegetation establishment and enhancement, as discussed in a later section. Specify sites for enhancement, as discussed in a later section. Specify sites for experimental work; indicate phasing of experiments and implementation of marsh restoration. Design experimental plots for comparison of alternative restoration techniques, where specific guidelines are not available (as discussed in a later section). Work with scientists to design the experiments.

8. Plan the monitoring phase of the project in conjunction with scientists who will conduct the experiments recommended above.

Considerations for designing buffer zones

The strip of land that separates development from environmentally sensitive wetland habitat has the function of protecting wetland species from the negative impacts of unnatural surroundings. In addition, the open space provides wetland wildlife with some features formerly available as transitional habitat. For species that fly into and out of wetlands, the buffer also protects the flight path so that aerial access is maintained.

Both the width and the character of the strip can be varied in designing the buffer zone, and the important question is which combinations of zone width and type will provide the necessary buffering capability. The Wetland Interpretive Guidelines (California Coastal Commission 1981) suggest that the *width* of the buffer can vary depending on the analysis of seven standards: biological significance of adjacent lands, sensitivity of species to disturbance, susceptibility of parcel to erosion, use of natural topographic features to locate development, use of existing cultural features to locate buffer zones, lot configurations and location of existing development, and type and scale of development proposed. The guidelines recommend 100 ft as the minimum for small projects and much wider buffers for larger projects such as subdivisions (ibid., page 21).

Criteria for determining the *quality* of buffers are also provided by the Commission Guidelines. Allowable features include access paths, fences, and uses that do not have significant adverse effects on the area being protected.

More recently, it has been suggested by the California State Coastal Conservancy (1982) that a combination of dense vegetation, fencing, and berms next to the wetlands channels will control physical access, visual disturbance, and noise.

Because different buffer designs have not been compared for their ability to protect wetland species from disturbance, it is difficult to make specific recommendations. Until narrower buffers are shown to be as effective as wider buffers, preference must go toward maximizing width. Screening density should also be maximized next to developments of high noise and visual disturbance. Fencing will usually be necessary to restrict access of people and pets.

Once a buffer has been designed to protect the wetland from disturbance, one should consider additional features that could further improve the restoration project. Buffers can go beyond the basic function of protecting wetland species from adjacent development. Some suggestions follow:

1. The buffer zone can provide habitat for native species that are characteristic of the transition habitats that normally occur between wetlands and uplands (see following section for vegetation recommendations). Native birds, insects, small mammals, reptiles, and amphibians may be able to use some of the buffer area; their presence should enhance the overall project.

2. The buffer zone can provide additional habitat for wetland species. In natural wetlands the transition zone provides habitat and space for wetland birds to avoid predation, to rest or "loaf," to escape high tides, to feed on transitional species such as insects, and to obtain nesting materials. Biological materials moving into the wetland from the buffer may be important to detritus-based food chains in the wetland.

3. The buffer topography may be a suitable site to plant rare and endangered plants. Although ecological knowledge of plant requirements is incomplete, ongoing research projects could benefit from the availability of habitat where establishment experiments could be performed. In saline substrates, the wetland plant, salt marsh bird's beak (*Cordylanthus maritimus* ssp. *maritimus*) is a candidate for such experiments – its natural habitat is within the upper salt marsh, but it may be possible to extend its distribution to higher elevations with experimental manipulation. Such "experimental gardens" could then

provide seeds or plants for reintroduction to habitats where the species has been eliminated. In non-saline substrates, an endangered vernal pool plant, the San Diego Mesa Mint (*Pogogyne abramsii*) might be grown for similar benefits.

Carrying out the above suggestions should lead to an improved restoration project. In addition, there are design concepts that could be carried out in one restoration project that would ultimately benefit later projects. Part of the buffer could be planned as an experiment to test the effectiveness of different widths or types of buffers. The major caution here, however, is to provide potential for future modifications – buffers that prove to be ineffective should be upgraded.

Recommendations for vegetation to plant in buffer areas

Native vegetation is recommended for use in buffering the upper salt marsh from development. The use of species from the upper marsh transition and coastal scrub vegetation types serves two purposes: maintenance is reduced because the species are drought tolerant, and the transitional habitat (now quite rare and usually highly disturbed) will be enhanced.

Choosing the species and their planting densities poses some problems because there are few examples of natural transitions to mimic. Nor are there examples of transition restorations to indicate which species will transplant most readily. To date, only one restoration project has focused on the transitional habitat. The Southwest Wetlands Interpretive Association has funding from the California Coastal Conservancy to restore part of the Tijuana Estuary. Their experience will provide much needed data on problems and successes.

For guidance in selecting species for buffer zones, refer to data on natural abundances of transition and coastal scrub communities. Neuenschwander et al. (1979) provide the only quantitative information on salt marsh transition vegetation, and their list of species and abundances is duplicated in Table 2. Although their data are from Baja California, the common species also

Table 2. Characteristics of the transitional plant community between upper salt marsh and upland vegetation at Bahia de San Quintin, 30°31′ N latitude, Baja California (from Neuenschwander et al. 1979). Data are average percent cover estimated visually in 224 quadrats and frequency of encounter in 2240 quadrats distributed among 14 sites. The range of values is given in parentheses in order to show site-to-site variability.

Bare ground accounted for nearly 30% of the space in the transitional zone at the time of the vegetation survey. Whether or not the bare spaces were seasonal ponds was not discussed by the authors. "Most of the transition zones occur on relatively steep slopes and vegetation changes are abrupt." (Ibid., page 168). Mean slope was indicated at 15%.

	% Frequency		% Cover	
Species	**Mean**	**Range**	**Mean**	**Range**
Monanthochloe littoralis	42	(7-49)	22	(0-55)
Salicornia subterminalis	39	(13-74)	21	(6-62)
Frankenia palmeri	32	(4-68)	19	(6-30)
Atriplex julacea	9	(1-24)	2	(0-6)
Limonium californicum var. *mexicanum*	7	(0-62)	2	(0-13)
Lycium brevipes	6	(3-11)	3	(0-6)
Frankenia grandifolia	5	(0-16)	2	(0-7)
Salicornia virginica	4	(0-21)	3	(0-21)
Atriplex watsonii	4	(0-18)	2	(0-16)
Gasoul nodiflorum = *Mesembryanthemum nodiflorum* (exotic species)	3	(0-25)		
Suaeda californica var. *californica*	1	(0-8)		
Cressa truxillensis var. *vallicola*	1	(0-7)		
Euphorbia misera	<1	(0-4)		
Dudleya brittonii	<1	(0-2)		
Distichlis spicata	<1	(0-5)		
Allenrolfea occidentalis	<1	(0-3)		
Aesculus parryi	<1	(0-1)		
Juncus acutus	<1	(0-1)		
Mammillaria dioica	<1	(0-1)		
Machaerocereus gummosus	<1	(0-1)		
Echinocereus maritimus	<1	(0-1)		
Haplopappus venetus	<1	(0-1)		

Table 3. Upland plant communities found near coastal wetlands.

Composition of the Southern California Coastal Scrub (from Mooney 1977)

Data are from Camp Pendleton in San Diego County

Dominant Species	Type of Plant
Rhus integrifolia	evergreen shrub
Eriogonum fasciculatum	drought-deciduous
Rhus laurina	evergreen shrub
Artemisia californica	deciduous shrub
Cneoridium dumosum	evergreen shrub

[Total Plant Cover = 99.5%]

Composition of Coastal Sage Succulent Scrub (from Mooney 1977)

Data are from low-elevation areas of San Pedro Martir, Baja California

Species	% Cover	Type of Plant
Agave shawii	8	leaf succulent
Machaerocereus gummosus	4	stem succulent
Echinocereus maritimus	<1	stem succulent
Mammillaria dioica	<1	stem succulent
Bergerocactus emoryi	1	stem succulent
Dudleya ingens	1	leaf succulent
Myrtillocactus cochal	<1	stem succulent
Opuntia rosarica	<1	stem succulent
Franseria chenopodifolia	18	drought-deciduous
Euphorbia misera	<1	drought-deciduous
Harfordia macroptera	2	drought-deciduous
Lycium californicum	<1	drought-deciduous
Galvezia juncea	<1	drought-deciduous
Rhus integrifolia	<1	evergreen shrub
Rosa minutifolia	16	drought-deciduous
Viguiera laciniata	<1	drought-deciduous
Simmondsia chinensis	7	evergreen shrub
Eriogonum fasciculatum	1	drought-deciduous
Ephedra californica	<1	evergreen
Rhus laurina	<1	evergreen shrub

occur in southern California marshes. The marsh transition would normally grade into coastal sage scrub and coastal sage succulent scrub communities, and species from these native habitat types should be considered for planting higher in the buffer zone. The species native to southern California and Baja California are listed in Table 3.

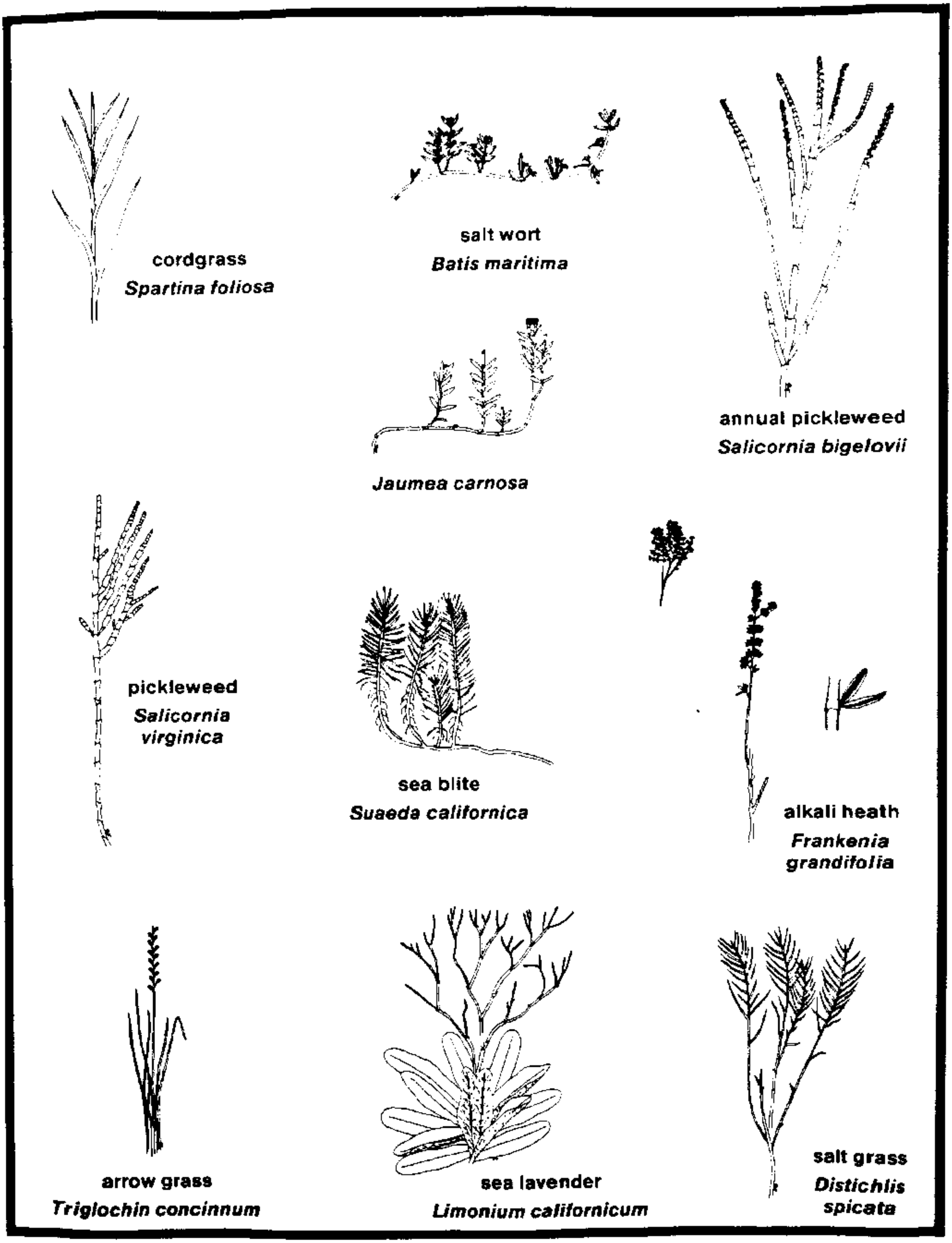


Figure 8. Common plants of southern California salt marshes.

TECHNIQUES FOR SALT MARSH RESTORATION AND ENHANCEMENT

Creating or enhancing a salt marsh ecosystem involves manipulating the environment, the species, or both. The characteristics of southern California salt marshes are described in detail elsewhere (Zedler 1982a), and only an overview is presented here.

The biological components to be considered in marsh restoration are the vascular plants (halophytes), the algae, and the various animal species. Because animals are likely to move into or out of marshes on their own in response to the availability of suitable habitat, it is often assumed that animals will utilize artificially created or enhanced habitats. In fact, no restoration project has been followed long enough to determine when artificial marshes match the wildlife value of natural marshes. There is a great need for research in this area, as encouraged in the monitoring section.

Salt marsh algae are also assumed to invade suitable habitats of their own accord because most are readily dispersed. Algal mats tend to develop on all wet substrates where light is available. Hence, transplantation should not be necessary, but again, this is an assumption. Whether or not the algal communities that develop are like those of natural marshes remains to be demonstrated.

Overall it is important to recognize that all components of the salt marsh ecosystem interact. Measures taken to enhance one component will have effects on others. In such cases fostering one component will augment another (e.g., denser cordgrass should benefit the light-footed clapper rail); in other cases, enhancing one component may dampen another (e.g., denser cordgrass canopies may reduce understory algal growth).

Providing suitable habitat for salt marsh vegetation

Tidal inundation, elevation, slope, soil salinity, wave force, and nutrients all interact to determine what halophytes occur in a salt marsh. Various disturbances also affect the vegetation, either by altering growth or by making space available to allow invasion. The patterns of occurrence seen in marshes such as Upper Newport Bay (Table 4) result from the interplay of all these factors.

1. Tidal influence. Salt marsh vegetation, in order to develop its natural potential, should be provided with tidal influence similar to that of natural marshes – that is, protected from wave force and strong currents.

Salt marshes occur naturally along protected intertidal shores. They also persist when tidal inundation is blocked by tide gates, sand bars, or dikes. Some of the species develop around inland depressions where water and salts accumulate (alkali flats). Salt marshes that have been removed from tidal inundation differ in various ways from those that are intertidal. Moisture collects from rainfall and runoff, and the wetland soil tends to impede percolation, so that the area is wet following winter rainfall and gradually drying through summer. Algal mats are less obvious with reduced soil moisture. Halophytes may either increase in biomass or decrease, depending on the soil moisture, salinity, and nutrient conditions of non-tidal wetlands (Zedler et al. 1980).

Whether or not salt marshes can be artificially established in non-tidal habitats has not been determined. Several species have been observed growing from seed in diked, seasonally wet areas of Ballona Wetland and Bolsa Chica Wetland, but whether seed would readily disperse into areas which lack remnant salt marsh vegetation is unknown. It may be possible and even desirable to transplant some species of halophytes into non-tidal areas, allow roots to take hold, and then open the area to tidal flushing. An advantage would be the ability to reduce soil salinity by watering with freshwater, thereby stimulating growth before subjecting plants to marine water. Such a procedure needs to be tested experimentally, comparing establishment rates with plantings in habitats that are intertidal from the onset.

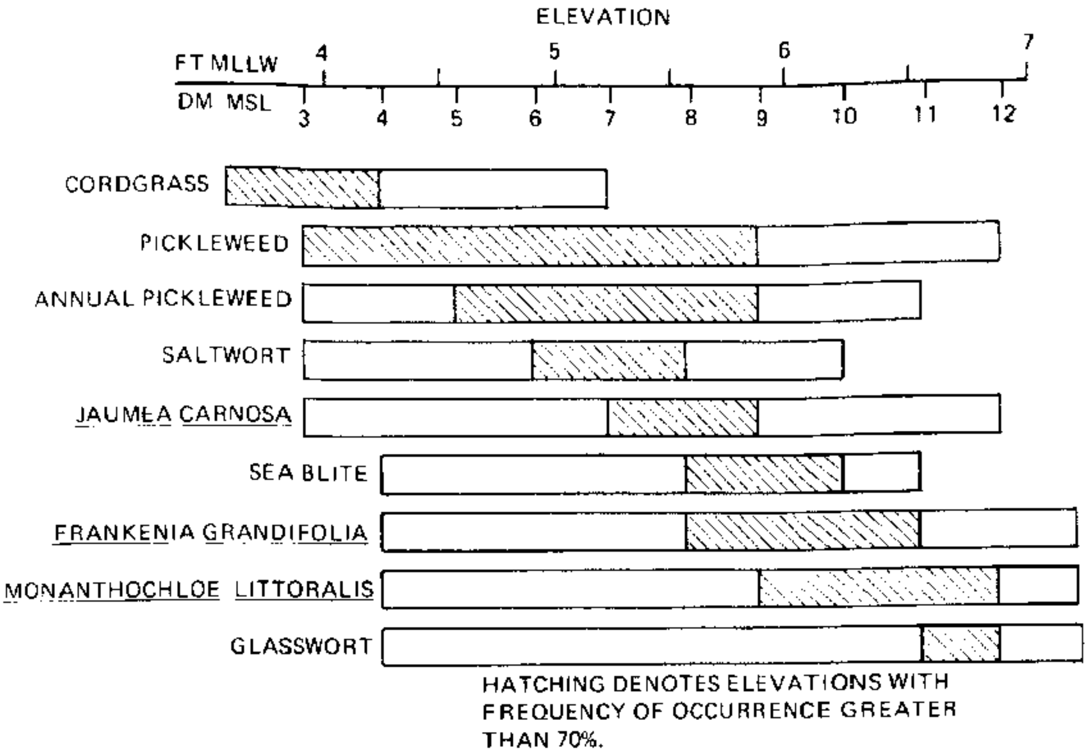
2. Elevation. Patterns of intertidal vegetation are readily referenced to elevation which serves as an indicator of moisture, salinity, and other substrate factors, all of which influence halophyte growth. Many of the relationships between plants and nutrients, plants and soil texture, etc., have not been worked out, but it is safe to conclude that elevation must first be suitable in order to expect success in establishing the desired halophyte cover. The elevation ranges occupied by nine common halophytes are indicated in Figure 9. Most species can occur over a broad range of intertidal elevations, but each has a peak abundance in different parts of the marsh. Contouring the topography to include MSL to extreme high water will provide suitable elevations for salt marsh species.

3. Slope. Natural salt marshes appear flat. Steep topography appears along some creek banks and sometimes as bluffs adjacent to the wetland. The relatively flat marsh topography reflects the conditions under which marsh sediments are laid down – quietly flowing water where fine particulates settle out. A typical transect across the vegetation at Tijuana Estuary's salt marsh (Zedler 1977) had only 1% slope. Thus, to represent the full range of intertidal vegetation would require a band approximately 200 yards wide extending from channels at MSL to transitional habitats at EHW.

Can steeper slopes support salt marsh vegetation? There are examples of steeper slopes within Tijuana Estuary's marsh, as well as elsewhere, but the maximum slope that can support salt marsh vegetation has not been identified. The best advice is to create relatively flat intertidal topography that slopes very gradually toward the intertidal channels. This has two positive attributes: there will be large areas available for salt marsh (cf. Fig. 10), and tidal water will not become impounded. Areas which are either too flat (0% slope) or not graded toward channels may impound tidal water and prevent vegetation growth. Even with grading, some intertidal pools may form with the shrinking of sediments. Unless such pools produce pests such as mosquitoes, they will be an asset to the marsh ecosystem. The additional habitat type will support algae and invertebrates, and may be used by killifish (*Fundulus parvipinnis*).

Will the topography be stable after tidal barriers are breached? Some accretion and erosion will occur. Hydrological engineers should be consulted early in the planning to ensure that major sediment redistribution is unlikely.

4. Soil salinity = interstitial salinity. Although natural marsh soils are usually



Most of the common salt marsh plants have broad ranges of distribution within the intertidal zone. However, each species differs in the elevation of most frequent occurrence (hatching). Data are from Tijuana Estuary (Zedler 1977) and Anaheim Bay (Massey and Zembal 1979). Reproduced from Zedler (1982a).

Figure 9. Salt marsh plant distributions across the intertidal elevation range.

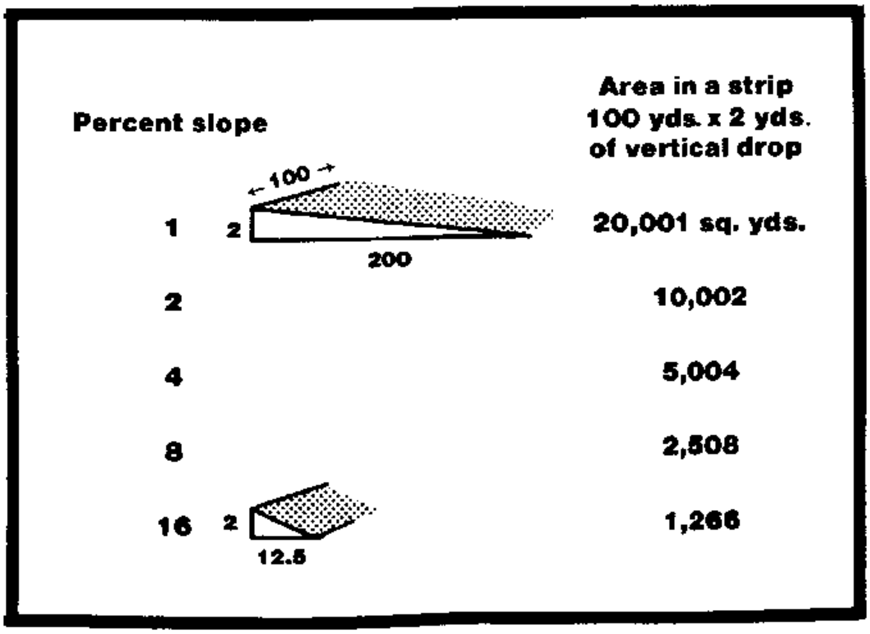


Figure 10. Comparison of area available for marsh vegetation given different slopes. All figures based on a strip 100 yards (91 m) long.

hypersaline, vegetation establishment will probably benefit from reduced soil salinities. Studies of salt marsh vegetation in the field (Zedler et al. 1980 and Zedler in press) and laboratory experiments (Barbour and Davis 1970, Barbour 1970) show that rates are improved when substrates are less saline than those found in natural marshes.

Experience to date indicates that cordgrass sprigs, transplanted into hypersaline soils (above 50 or 60 ppt) will have high mortality. Pickleweed grows in much more saline soils than cordgrass but too few experiments have been done with this species to identify permissible planting salinities for southern California.

Watering with soaker hoses is proposed as a mechanism to improve transplantation success in hypersaline areas. As mentioned in the discussion of tidal influence, areas that are diked could be flooded with fresh water to reduce soil salinities for transplantation prior to making the area tidal.

Can soils have too little salinity for the

Table 4. Composition of the Salt Marsh at Upper Newport Bay (from Vogl 1966)

	Lower Marsh		Middle		Upper Marsh	
	% Freq.	% Cover	% Freq.	% Cover	% Freq.	% Cover
Spartina foliosa	88	38	19	1	<1	
Batis maritima	5	4	88	15	22	1
Salicornia virginica	13	4	84	23	70	40
Suaeda californica	1		6		15	2
Frankenia grandifolia			26	3	30	2
Distichlis spicata				2		5
Triglochin maritima			42	11	10	1
Limonium californicum			10	1	20	1
Monanthochloe littoralis			1		45	15
Cuscuta salina			3		2	2
Spergularia marina			1			
Jaumea carnosa					4	
Juncus acutus					4	2
Gasoul chilense					1	
Scirpus californicus					1	14
Salicornia subterminalis					7	

Frequency of occurrence was tallied in 600 quadrats; percent cover was assessed visually in 240 quadrats.

establishment of salt marsh vegetation? Yes. Soils that are fresh to slightly brackish will allow natural invasion of species from fresh water marsh and brackish marsh habitats. In the San Diego River Marsh (Zedler 1981) there was rapid invasion of *Typha domingensis*, *Scirpus robustus*, and *Pluchea purpurascens*, all of which are absent in saline habitats. Once established under low salinities, the *Typha* and *Scirpus* have both persisted, even under salinities of 25 to 33 ppt. From this experience, it appears prudent to reduce soil salinities briefly and only to brackish conditions. The reduction of Tijuana Estuary marsh soils to 15 ppt after the 1980 flood was not followed by invasion of glycophytes. Without further study of invasion under different salinity regimes, these findings must be used as a guideline, and these recommendations should be implemented as experiments, with careful records of results under different planting conditions.

The salinity of moist soils is easily measured with a salinity refractometer (available from most scientific supply houses for about $500). A drop of soil water can be squeezed onto the refractometer using a syringe (sans needle) fitted with a small circle of filter paper onto which a small sample of soil is compressed. Salinity is read directly on

Figure 11. Some experimental sites proved unsuitable for cordgrass establishment. This exposed bank in San Diego Bay had high wave force and was subject to sediment movements as well as accumulations of floating algal mats. Cages made of aviary wire were placed over alternate sprigs of cordgrass transplants to prevent herbivory. However, mortality of plants both within and outside cages indicated that grazers were not the limiting factor.

a scale from 0-150 or more parts per thousand, depending on the instrument. Dry soils must first be wetted, and procedures for mixing standard soil pastes are given in Richards (1954).

5. Wave force. In some parts of the world (e.g., The Netherlands) *Spartina* is deliberately planted to control shore erosion and to foster sediment accretion. In other places (e.g., Great Britain), hybrid strains of *Spartina (S. townsendii = S. alterniflora* x *S. maritima)* are considered weeds because their vigorous invasion of mudflats modifies shorebird feeding habitats and accelerates the filling-in of wetlands. In the United States, research to utilize *Spartina alterniflora* for controlling eroding shorelines has been actively pursued, especially for stabilizing dredge spoils (Woodhouse, Seneca and Broome 1974).

Can *Spartina foliosa* withstand heavy wave action and be used to similar advantage? Probably not in southern California. Transplantation of cordgrass to dikes in San Diego Bay met with nearly 100% mortality. The site experienced heavy wave action, shifting of sediments, and deposition of floating algal mats (*Ulva* sp.). High soil salinities and steep banks were complicating factors, so it is not certain that wave force was responsible for all of the mortality (Fig. 11). However, the experience suggests that cordgrass is not a panacea for slowing the erosion of steep banks.

6. Nutrients. Nitrogen may be limiting to plant growth in the proposed marsh substrates. Phosphorus is rarely limiting to salt marsh growth, although it can enhance productivity if nitrogen is also added. We have successfully increased the growth of pickleweed (*Salicornia virginica*) sevenfold by fertilizing with urea (application rate = 10 gN/m^2 biweekly) in the San Diego River Marsh (1977 data of Dennis Turner, unpublished). Additional experiments with cordgrass are underway, and we expect to work out recommendations for determining when fertilization is needed.

7. Toxic compounds. The soils of many sites made available for salt marsh establishment may contain heavy metals, toxic hydrocarbons, or both, especially if they result from dredging. At present, the concentration of these materials that various salt marsh species can tolerate is not known. The Port of San Diego is obtaining extensive information on the soils of their San Diego Bay dredge spoil island. Ultimately they will be planting halophytes and assessing their success in marsh establishment.

Summary of specifications for salt marsh habitat construction

Create intertidal topography (MSL to EW) with low slope (1-2 % is probably ideal) and with protection from waves. If substrates are hypersaline or become hypersaline after construction, take measures to reduce soil salinity prior to planting. Either wait until winter rains have reduced salinity or irrigate with fresh water. Examine the potential for using wastewater to water and fertilize simultaneously.

Establishing marsh vegetation

Salt marsh vegetation may establish naturally once a site with the above characteristics is made available. However, it may take years or decades before a community of plants similar to those at Tijuana Estuary, Upper Newport Bay, Anaheim Bay, or Mugu Lagoon develops. Many of the plant species appear to have limited ability to invade bare substrates. Pickleweed (*Salicornia virginica*) is the most opportunistic invader of intertidal substrates. It has the broadest range of tolerance for wetland habitats and becomes abundant over a wide range of elevations (Fig. 9). Nearly monotypic stands have developed in areas of known disturbance history, e.g., the San Diego River Marsh following flood control channel construction and San Francisco Bay's Hayward Marsh following dike removal (Niesen and Josselyn 1981).

Why don't other species invade as rapidly? In some cases, the limiting factor is soil salinity that is too high for seedling establishment; in other cases, there simply may not be seeds available.

Is there an easy way to find out what limits seedling establishment? Some simple experiments can help differentiate between the soil salinity and seed availability. We recently developed a technique to explain low seedling density at the San Diego River Marsh, and a slight modification should work nicely to "bioassay" substrates for marsh establishment. The method uses pickleweed seeds (*Salicornia virginica*) which can be collected in late summer - preferably from sites where the species is very abundant. Permits are required for seed collection in reserves, State Parks, or other refuges. Seeds can be shaken from the dried tips of mature fruiting branches without uprooting or damaging the plant.

Map 1. The broad flat coastal plain near Los Angeles provided extensive habitat for salt marshes in the 1890's.

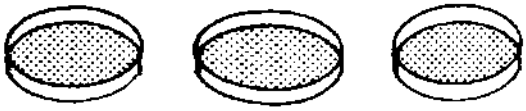
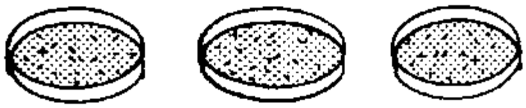
Treatment	Results and Interpretations
A: Saline soils without seeds added 	**If salt marsh plants germinate in all three containers, your soils are likely to develop vegetation without assistance.**
B: Saline soils with seeds added 	**If germination occurs here but not in A, seeds are probably limiting, and some planting is in order.**
C: Leached soils without seeds added 	**Good germination in this treatment but not A or B indicates that salinity is too high and watering may be required or waiting until heavy rainfall occurs may be necessary.**
D: Leached soils with seeds added 	**Germination in D alone indicates that both salinity and seed sources are limiting. Watering and planting are recommended.**

Figure 12. A simple bioassay of soils.

NOTE: This bioassay will indicate what amendments are necessary for pickleweed establishment, but because pickleweed is somewhat more tolerant of soil salinity than cordgrass and perhaps other marsh species, it may not be indicative of amendments needed for all possible transplant agencies (Fig. 12).

Collect a bucket of surface soil (top ½ inch) from the proposed intertidal marsh site. Measure soil salinity. If it is 20 ppt or higher, it may be limiting germination. Measure out about 12 similar subsamples of the soil and treat in the following way:

Place 6 in flat containers with clear lids (e.g., plastic wrap). Add a large number of pickleweed seeds to 3 of these 6 containers (germination may be 50 %; so add seeds in excess). Place 6 into funnels lined with large coffee filters. Pour freshwater through these soils until the leachate is reduced in salinity to 0-5 ppt.

Decant the soils into 6 flat containers with clear lids. Add pickleweed seeds to three of these 6 containers. Keep containers in natural light and keep moist for a month.

Assess seedling germination success and refer to Fig. 12 to interpret findings.

What to plant?

The most common species of salt marsh plants are listed in Table 4 with selected attributes which may influence the choice for planting. Two species are especially important for providing endangered bird habitats (pickleweed and cordgrass). Another species, not listed because it is itself endangered, is the salt marsh bird's beak, *Cordylanthus maritimus* ssp. *maritimus* (see page 39 for special discussion). If the marsh restoration goal is to assist the recovery of endangered species, then these three species will have high priority for planting.

If the restoration objective is to establish vegetation similar to that found in less-disturbed salt marshes, then a variety of species should be introduced to the area. If public approval of the project is an important consideration, then some of the plants with showy flowers should be strategically placed near access points. *Limonium californicum* and *Frankenia grandifolia* have lavender flowers and attractive foliage.

Where do I get material to plant?

Most of the species will have limited availability for collection, or will be found mainly in areas where collection is prohibited. The best source of plants and seeds is from the salvage operation prior to site construction. The next most desirable is a nearby site that will be altered by development or restoration. Material should never be brought in from distant wetlands, as this will contaminate the local gene pools and may reduce success if alien populations cannot tolerate southern California's hot, dry summers.

The source of propagules for establishing salt marshes will continue to be a limiting factor until native-plant nurseries gear up to meet restoration needs. In the meantime, it is recommended that an on-site nursery be established specifically for the purpose of supplying future materials for site restoration.

Plantings will thus be phased in the following sequences:

1. Choose the most favorable part of the site for an on-site nursery in order to maximize growth and reproduction. Plant this nursery with the largest number of species desired for the future marsh. This will also serve to determine which species will grow well on the site. Plant individual species well apart from one another to facilitate future replanting. A sample scheme is presented in Fig. 14. Planting techniques are treated in the next section.

Figure 13. Wetland plants are too valuable to destroy. Salt marsh vegetation is being salvaged prior to resculpturing the topography and increasing the tidal circulation at Cabrillo Marsh in this project sponsored by the Port of Los Angeles. Plants are moved to a holding area and irrigated daily prior to transplantation after site preparation.

Table 5. Plant characteristics to keep in mind when planning an artificial marsh.
Note: all of the following plants except *Salicornia bigelovii* and *Suaeda californica* spread vegetatively.

1. Cordgrass (*Spartina foliosa*)
   - tall grass
   - desirable wildlife habitat
2. Saltwort (*Batis maritima*)
   - succulent
   - spreads very well by runners; some 5-6 feet long
   - rarely form dense cover in southern California
   - most plants grow close to the ground
   - older leaves usually drop off in summer, leaving tufts of young leaves at ends of bare branches
   - flowers are inconspicuous on oval fruitlike structures, which also break off
3. Annual pickleweed (*Salicornia bigelovii*)
   - germinates after winter rains, produces seed in late summer and dies
   - has the highest germination and seedling establishment rates in natural marshes
   - usually grows with saltwort
4. Pickleweed (*Salicornia virginica*)
   - succulent
   - most widely distributed species in southern California marshes
   - tolerant of a wide variety of conditions, from low to high elevations
   - does occasionally spread by seed/seedlings, but usually spreads vegetatively
   - growth form varies with environmental conditions, from short and bushy at higher elevations to tall and spindly at low elevations
   - can reach 3 feet in height and produce dense canopies under brackish conditions after plants are well established
   - flowers are inconspicuous; taller plants are used by Savannah sparrow for nesting
5. *Jaumea carnosa*
   - succulent member of the sunflower family
   - produces yellow flowers
   - spreads well; can send out long runners under low salinity conditions
   - can be propagated from rhizome sections
6. Arrowgrass (*Triglochin concinnum*)
   - succulent grasslike species
   - early growing and flowering plant; leaves are small; flowers not showy
   - dies to ground after its early-spring activity period
7. Salt grass (*Distichlis spicata*)
   - mat-forming grass, similar to Bermuda grass in appearance
   - can form pure, thick stands, but is usually not abundant in natural marshes
   - seems to do best in sandier conditions
   - tolerates drought
8. *Frankenia grandifolia*
   - bushy plant with reddish stems and dark green leaves – very attractive
   - produces small but pretty lavender flowers
   - can be stored for at least 2 months in cold room conditions (roots in water)
   - can form pure stands
9. Sea lavender (*Limonium californicum*)
   - the showiest of the marsh plants – sends up a tall fruiting stalk with tiny lavender flowers; related to stattice
   - large broad leaves in a basal rosette
10. Shoregrass (*Monanthochloe littoralis*)
    - low, mat-forming grass
    - spreads well into open areas by sending out long (3 feet or more) runners
    - good stabilizer
    - leaves are short and prickly
11. Sea blite (*Suaeda californica*)
    - succulent
    - rarely forms pure stands
    - usually occur as isolated individuals
12. Glasswort (*Salicornia subterminalis*)
    - succulent
    - low bushy perennial of the high marsh
    - can form pure cover, but often is mixed with *Monanthochloe littoralis*

2. Collect seeds for sowing elsewhere on the site, choosing the elevation where growth of that species was greatest. Save seeds until the next rainy season, and work seeds into the surface soil after soil salinity has been reduced by rain or irrigation.

Planting techniques

All of the species produce seeds, and many reproduce vegetatively as well. Hence, depending on the species, there may be a choice of using seeds or transplanting shoots.

Success of transplantation is greatest when whole plants are moved because root systems are not disturbed, but this is also the most damaging technique for the source area. Hence, it is recommended only for high-risk establishment sites – i.e., where salinity cannot be sufficiently lowered; where wave force may be too strong.

Our experimental work has dealt mainly with cordgrass because of its importance to endangered species and because it is known to have declined in southern California salt marshes. Results from our work have shown that

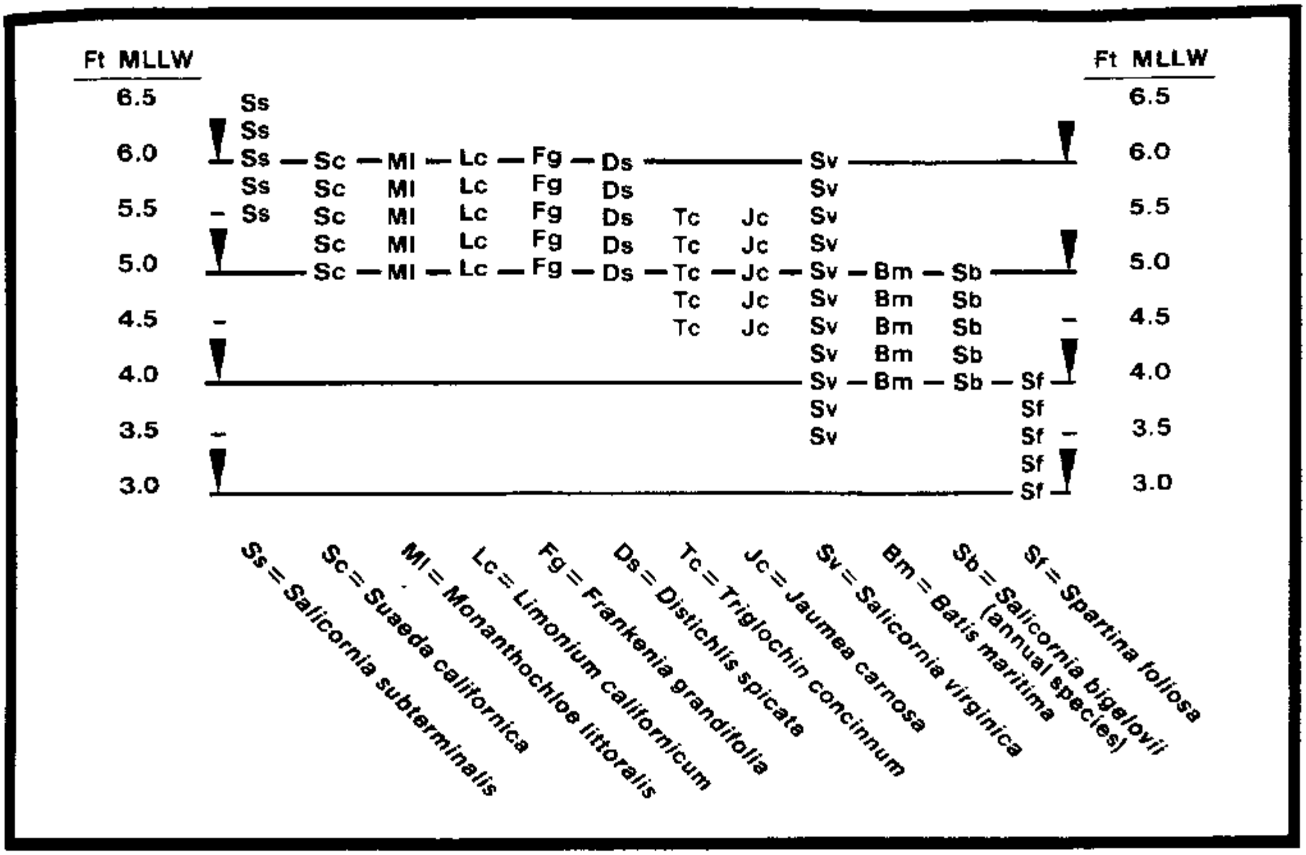


Figure 14. Suggested planting scheme for a resource garden – a high diversity demonstration plot from which future transplants might be taken. Allow room for expansion between species rows. Mark elevations with stakes and follow success of each species at different elevations for aid in future transplants. [Recommendations follow from species distributions at Tijuana Estuary (Zedler 1977)].

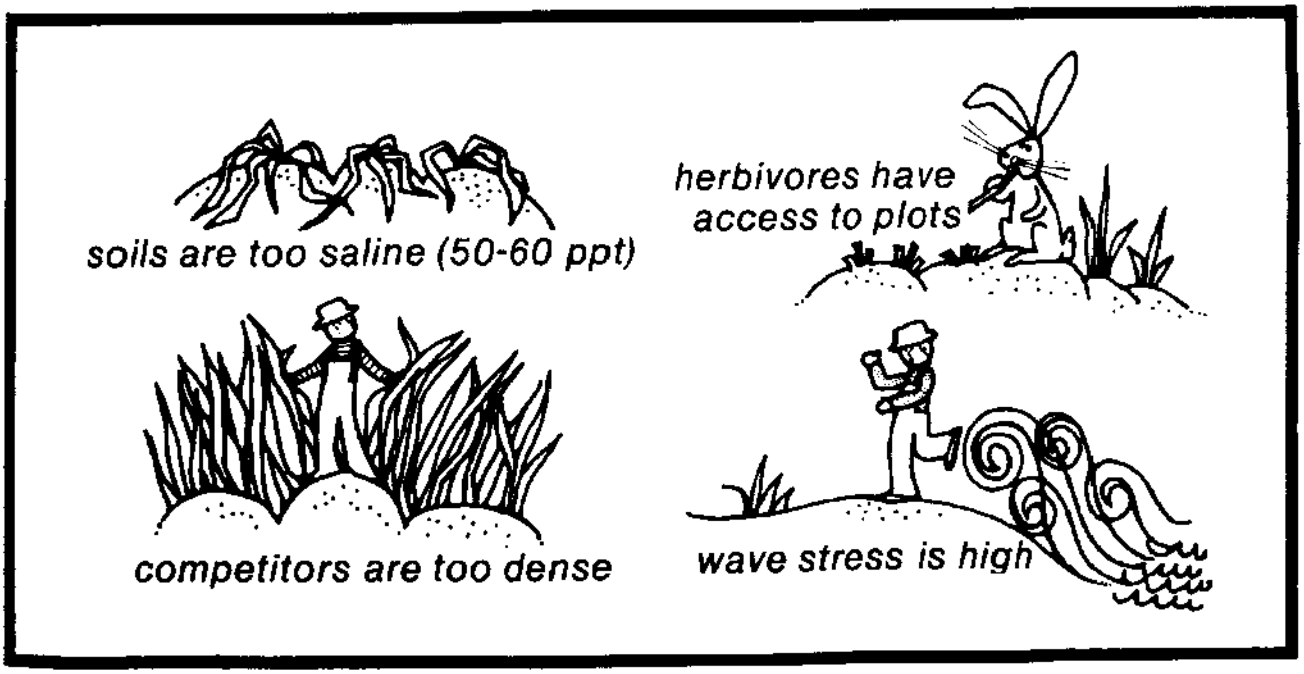


Figure 15. Past experiments have shown that cordgrass transplantation doesn't work when these conditions exist.

seed germination and early growth are the critical stages for establishing cordgrass, but that herbivory and competition with more opportunistic marsh species can limit growth and survival after the initial establishment.

Establishing cordgrass: from seed to successful establishment

1. Seed collection. Cordgrass flowers in late summer and generally produces seed in October. By late December, many seeds will have fallen from the plants, so that the ideal collecting time is November-early December. Seed production is highly variable both within and between salt marshes. Healthy robust seeds will have the highest germination rate and patches of good seed should be sought before collecting. Collecting in itself is disturbing to marshes. Whole inflorescences can be clipped from the plants into paper bags for transport to the storage facility. Inflorescences often develop black fungal growths and may be infested with granivorous beetle larvae. We saw no evidence that such infloresences cannot produce viable seeds. Rather, it appeared that during the years of infestation all inflorescences *can* become infested; those without smut may simply be younger.

Seed production at Tijuana Estuary estimated from collections in fall 1979 was estimated as follows:

> 15 inflorescences per m^2 in low marsh
> approx. 70 seeds/inflorescence
> approx. 1,050 seeds/m^2

However, most of these seeds were not viable. Of the seeds collected, only about 17 % were viable, so that collecting 15 inflorescences might yield about 175 viable seeds.

Seed viability can be determined with tetrazolium dye (uptake indicates viability) or by eye (robust-appearing seeds). The visual method suggests higher rates than tetrazolium, sometimes as much as twofold.

Comparison of seeds collected at various sites at Tijuana Estuary and the San Diego River showed high variability of germination. Low germination rates were attributed to shedding of good seeds prior to collection (indicating the need to watch populations carefully and collect shortly after seeds become plump).

2. Seed storage. After collection, cordgrass seeds should be allowed to ripen by storing them underwater in a cold room for one month.

Salinity of the storage water does not strongly affect germination rate (based on trials using 0, 70 and 100% seawater = 0, 24, and 34 ppt). All storage was in a dark 41°F (5°C) cold room.

Germination rates decline quite rapidly with storage times longer than one month.

3. Laboratory germination of seeds. After seeds have ripened under cold storage, they can be germinated by the following technique. Rinse with a 25% Clorox bleach-75% freshwater solution to reduce spoilage. Place on filter paper in covered petri dishes and provide alternating light/dark conditions with warm temperatures. We achieved faster germination (but not higher %) using 12 hr light at 35°C/12 hr dark at 20°C than with 25°C days and 15°C nights. Seeds should be watered with fresh water, as saline conditions at this point reduce germination. The highest rate obtained from plump viable-appearing seeds (not from random assortment of seeds collected) was 85% after 95 days of incubation in a growth chamber.

Attempts to stimulate germination with potassium nitrate were ineffective, while use of kinetin, gibberellic acid, and thiourea and the slitting of seed coats were actually detrimental.

4. Seedling growth. Seedlings can be grown in plastic pots set in pans of water, with enough moisture to keep soil saturated. Seedling survival was higher (42%) in continuously saturated soils than in flats watered at intervals by a drip system (11% survival). Seedlings grew best under greenhouse conditions. Outdoors, fresh water and shade were advantageous, suggesting that cordgrass seedlings are poorly adapted for establishment in exposed environments thereby explaining their rarity on exposed mudflats.

Controlled experiments with seedling growth under three levels of shading (100, 43 and 30% light) and with pots flooded with three types of water (0, 24, and 34 ppt = seawater) did not yield significant differences among treatments. However, growth under fresh water conditions may have been reduced by higher rates of insect grazing. About 50% of the seedlings grown in fresh water were grazed, compared to 9% and 4% for brackish and seawater treatments. Therefore, it is recommended that seedlings be reared in slightly brackish water with some shade and protection from insect damage.

Summary of success in growing seedlings for field transplantation

Beginning with 100 seeds which were assumed to be viable from their robust appearance, an average of 17 plants were produced for field transplantation. The critical stages were seed germination and early seedling growth, as indicated in Table 6.

1. Seedling growth studies. If seedlings need to be retained prior to field transportation, it is recommended that they be given increasing amounts of light under freshwater conditions. Seedlings kept in the greenhouse experience etiolation (tall growth with pale color), while

Table 6. Germination and early establishment limit cordgrass establishment

Nov-Dec 1 Mo.		1 Mo.	1-2 Weeks	1-2 Weeks	Feb-Apr 1-2 Weeks
Collection in field + ripening	robust 100/seeds	47 germinate in petri dishes	38 survive to be potted	18 survive potting procedure	17 survive to be transplanted to field
Survival:		47%	80%	48%	95%

those moved to full light develop a larger number of new shoots.

Experiments beginning with about 7 cm high seedlings and grown an additional 12 weeks gave the following results:

Table 7. Seedlings grow best if started in the greenhouse

Treatment	Average height after 12 wks growth	# Shoots as a % of # at start of experiment
Grown inside greenhouse 12 wks	32 cm	100-500%
Grown outside for 12 wks	8 cm	75-100%
Grown inside 2½ wks, then moved outside for 9½ wks	14 cm	175-325%

Comparison of seedling survival and vegetative propagation with salinities gave these results:

Table 8. Low salinities foster growth

Treatment	# Shoots as % of # at start of experiment	
In flowing water trays (outdoors)		
Seawater (34 ppt)	41%	(heavy mortality)
Brackish water (24 ppt)	68%	(some mortality)
Fresh water (0 ppt)	265%	(good vegetative reproduction)
Transplanted to San Diego River		
Marsh with low soil salinity (5-20 ppt)	206%	(good vegetative reproduction)

2. Propagation of rhizomes. Propagation from rhizome segments is not likely to be feasible. Our attempts to grow segments of one- and two-node length and tip sections of the rhizome yielded only a few plants from the tip sections. All were grown in floating aquaculture (hydroponic) conditions under various salinities. Various attempts to grow rhizome segments in sand, soil, and water in the greenhouse and outdoors did not succeed.

3. Attempts to increase vegetative reproduction in the lab. Sprigs grown in pots for 2 weeks and pruned to 5 cm height as a possible technique for increasing vegetative reproduction experienced heavy mortality. Plants held in nursery conditions should be protected from high light, high salinities, and herbivory. They do not adapt well to traditional pot culture.

4. Seed germination in the field. Cordgrass seedlings are distinguishable from vegetative sprouts by their narrow leaves, small stem diameters, and generally more delicate appearance. Only rarely have such seedlings been observed in southern California marshes. During our July 1980 survey of cordgrass expansion along the abandoned sewage lagoon at Tijuana Estuary, we located a small number of plants that were isolated from larger patches (e.g., several meters away). Excavation of one of these patches indicated no vegetative connection with other patches (Fig. 16), and we conclude that the new plants arose from seed. The seedlings were found after a winter of heavy flooding and marsh soils of unusually low salinity (Zedler in press). Other annual surveys of cordgrass (monitoring 100 locations within the less disturbed marsh at Tijuana Estuary from 1979-present) have failed to locate plants that look like seedlings.

Experiments to establish cordgrass seedlings were set up on February 2, 1981 near naturally occurring cordgrass patches (again, along the shore of an abandoned sewage lagoon at Tijuana Estuary). No seedlings were found in April or July of 1981, despite rather elaborate attempts to create suitable conditions. The experiment included 3 replicate plots for each of 4 treatments: seed scattered under normal pickleweed canopy; seeds buried; seeds placed on raked soil; seeds placed on soil after algal mat was removed. Each plot was sown with approximately 490 seeds, for a total of nearly 6,000 seeds. Lack of germination may have been due to the high soil salinities during the relatively dry winter (the planting site had salinities of 42-48 ppt on Feb. 27 and 52 ppt on July 6, 1981). All seeds had been collected in Nov. 1980 and stored underwater in the cold room.

5. Growth of seedlings in the laboratory. Seedlings were reared in the greenhouse in plastic pots set in about an inch of tap water. Plants held in the greenhouse tended not to multiply vegetatively in the 10-13 week observation period while those which were transferred outdoors and grown for a total of 17-21 weeks doubled in density, as seen in the following table.

To encourage vegetative expansion of cordgrass seedlings, move plants out of the greenhouse once they appear to

Table 9. Comparison of seedling multiplication rates (all data from 1980)

Dates	Time inside greenhouse Weeks	Time outside (weeks)	Number of original seedlings remaining on 7/21	Number of new side shoots on 7/21	Percent increase
3/13-4/22	5+	15	3	16	223
4/17-4/25	1	16	18	21	217
5/10-7/16	10	3	6	4	167
5/30-7/21	8	2	22	0	0

have established a good root system. We attempted but were unable to root side shoots which we broke off the "parent seedling."

6. Transplantation of seedlings to the field. It appears that seedlings grown in fresh water can be transplanted to the field even during the stressful conditions of summer. The first seedling transplantation experiment took seedlings which were grown in fresh water, first in the greenhouse and later outdoors (see Table 7).

One hundred seedlings from 19 pots (see Table 9) were transplanted to the shore of an abandoned sewage lagoon at Tijuana Estuary on August 8, 1980. A census on October 20, 1980 (when the soil salinity was 35-37 ppt) showed that all pots had survivors, and density had increased vegetatively to 155 individuals. Seedlings that began growth on March 13 had the poorest success on transplantation to the field (93% survival) while the other three batches all continued to increase in density (from 156 to 300%).

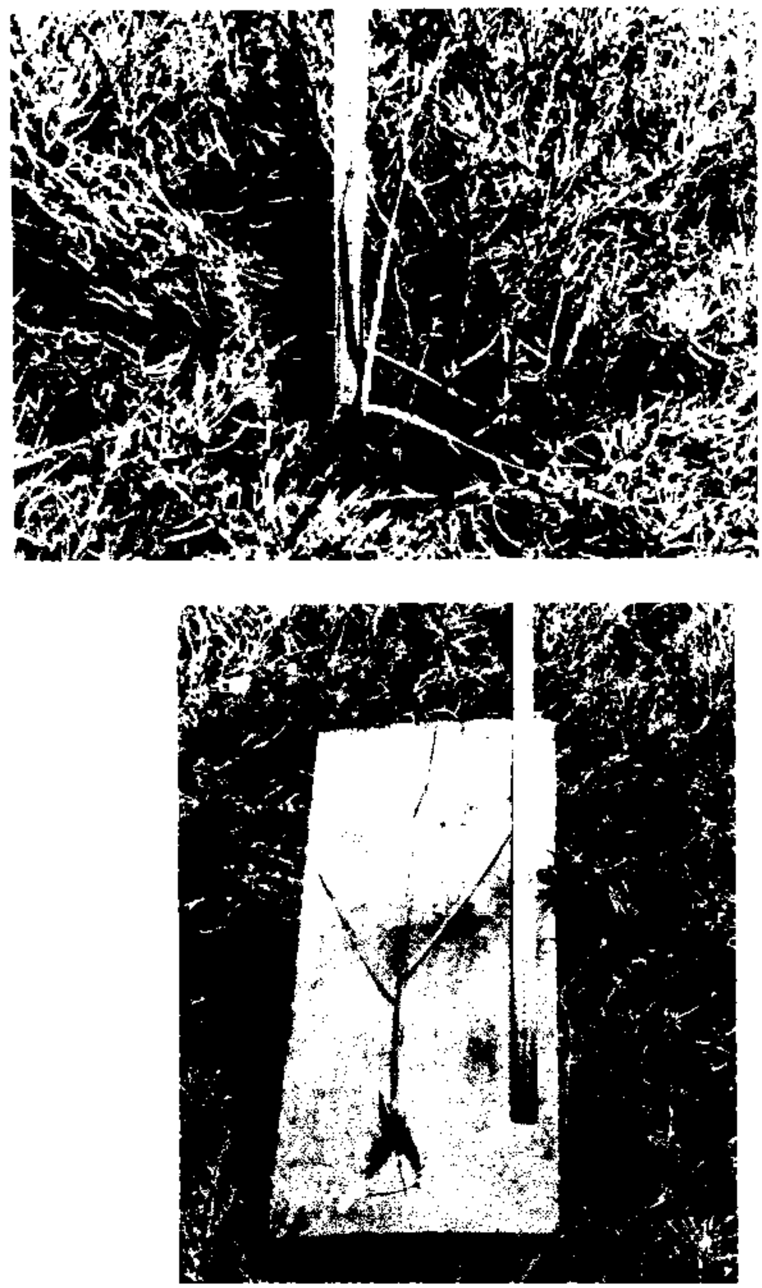


Figure 16. Cordgrass seedlings are rare in the salt marsh, but several were found after the 1980 floods reduced soil salinities at Tijuana Estuary. Lack of a rhizome connection (lower photo) indicates that the plant is not a vegetative sprout but a seedling.

Table 10. Plants can be reared in fresh water and transplanted directly to saline soils

Seedlings grown in:	Number set out on 10/20/80	Number of survivors on 12/8/80	Number of survivors on 2/27/81
Fresh water	170	153 (90%)	113 (66%)
Brackish water	114	103 (90%)	94 (82%)
Sea water	36	35 (97%)	30 (83%)

Experiments to compare survival of seedlings grown at different laboratory salinities outdoors showed little initial difference in survival after being planted on the bare shore of an abandoned sewage lagoon at Tijuana Estuary (35-40 ppt soil salinity, Table 10.)

However, long-term survival (4-month census) was significantly lower among seedlings reared in freshwater. While the cause of mortality at this state is unknown, it must relate to something other than transplant shock.

7. Growth of shoots transplanted from field to laboratory. Shoots taken from marshes for future transplantation should be held in pots set in flowing water tables.(Table 11).

8. The influence of soil salinity and grazing on transplantation success. Field experimental plantings of cordgrass (whole plants in soil cores) were undertaken to determine if transplant shock, source of plants, or soil salinity of transplant "garden" affected transplant survival. Of these factors, only soil salinity was a problem, and on this basis, it is recommended that sites with more than 50 ppt be desalinized prior to transplanting cordgrass.

These early experiments with cores also indicated the severity of the grazing problem. Two kinds of grazers appear to damage plants – birds which eat leaf tips and small mammals which bite off stems and eat the pith.

Results of the core transplant experiments show that growth can be substantial if plants are placed in suitable soils and escape grazing (Table 12).

Table 11. Holding plants in low salinity conditions improves survival, height growth, and flowering

Shoots held in:	%Survival	Average maximum height (cm per pot)	%Flowering
Fresh water (0-05 ppt)	128*	77	57
Brackish water (20 ppt)	91*	67	20
Seawater (34 ppt)	38	48	4

*Vegetative reproduction occurred in some plants.

Figure 17. CALTRANS developed an intertidal cordgrass nursery near San Diego Bay to hold and propagate plants for later use in marsh restoration. Plants were salvaged from a patch near Freeway 5 that was destined to be filled for highway widening.

Table 12. Comparison of transplant success – whole plants in soil cores: Transplanted in spring, censused in August 1979

Control = test of transplanting method within cordgrass habitat

Planted 2 22 79 at Tijuana Estuary;
9 out of 10 cores survived

Best success = 94% survival after 4 months at Tijuana Estuary abandoned sewage lagoon (mudflat habitat)

Planted on 4 5 79 with 46 ppt soil salinity;
31 out of 32 cores survived

Intermediate success = 10-83% survival with some cores showing substantial vegetative expansion in diameter of cordgrass canopy

Planted on 3/6/79 at San Diego River mudflat with 34 ppt soil salinity; 11 out of 12 cores survived; maximum expansion = 1.0 meter diameter

Planted 6 12 79 at Tijuana Estuary within cordgrass community (to serve as a control on transplanting method) with 36 ppt soil salinity; 9 out of 10

Planted on 2 22 79 at San Diego River mudflat with 25 ppt soil salinity; 1 out of 10 cores survived, but the surviving transplant expanded 1.6 meters in diameter in 2 months, and by the end of the next growing season, the patch had expanded to a diameter of 8-10 meters

Poorest success = 10% survival and no vegetative expansion of survivors

Planted on 2/22/79 at San Diego River mudflat with 21 ppt soil salinity; 0 of 10 cores survived, grazers eliminated plot

Planted on 2 22 79 at San Diego River mudflat with 37 ppt soil salinity; 1 of 8 cores survived; grazers eliminated plot

Planted 3/20/79 at San Diego River mudflat with 80 ppt soil salinity; 1 of 12 cores survived; salinity probably was major stress

Planted 3/22/79 at San Diego River mudflat with 61 ppt soil salinity; 0 of 12 cores survived; salinity probably was major stress

Using whole plants in soil cores, it was possible to transplant cordgrass throughout the growing season. However, in many areas, soil salinity will increase through early fall, and chances for successful transplantation will decline.

Of all these transplanted cores, one of the February 1979 plants had an outstanding success, expanding to an 8-10 meter patch by July 1981 (Fig. 18). Part of the explanation for its good growth was the low soil salinity in the San Diego River channel following the 1980 floods and subsequent freshwater runoff from irrigation in the watershed. Soil salinity was reduced to 0 ppt in winter 1980, but became as high as 33 ppt in fall of 1981. It then declined again and was only 25 ppt in June 1982.

9. The influence of nitrogen fertilization, removal of competitors and protection from grazing on cordgrass transplants. The high mortality of transplants in the early experiments suggested a number of additional techniques to improve cordgrass growth. In the following work, sprigs of cordgrass were used to reduce the work load in transporting plants. Sprigs were collected from creek banks at Tijuana Estuary, held in buckets of creek water, and often stored

Figure 18. Under conditions of low soil salinity, low wave force, and low grazing pressure, transplants of cordgrass can be highly successful. This 8-10 m diameter patch arose from a single stem planted two growing seasons prior to the photograph.

several days in a dark cold room with no apparent harm

Three experiments were set up in the San Diego River on December 10, 1979 to determine the effects of fertilizing with urea of removing the existing canopy of pickleweed to reduce competition; and of caging plantings with aviary wire (¼ inch mesh) to exclude grazers. These first plantings were observed for about a month.

The rainfall in winter 1980 was extremely heavy and flooding was severe (soil salinity was 5-10 ppt by January 15). All the above plantings were washed away by March 24, 1980. Following the January and February rains, an upstream reservoir was lowered for additional flood protection, and fresh water continued to flow into the marsh well beyond the natural rainy season. The dominant pickleweed vegetation was killed and replaced by rapidly invading cattails (Zedler 1981).

The transplantation experiment was repeated in a similar fashion, with two modifications: sprigs of cordgrass were collected on 4/23/80 and planted on 4/30/80 in areas where cattails had and had not been cleared. Fertilizer was added at the rate of 10 g urea/m^2 concentrated near the base of each sprig on 4/30/80. Urea was added again 7/3/80 using the 1970 procedure. The urea additions of 4/30/80, concentrated at the base of each sprig, were highly detrimental. Mortality was evident by 5/20/80, and fertilized plots continued to decline through the 1980 growing season.

Removal of overstory vegetation had an enormous effect on vegetative growth and reproduction by cordgrass. After 8 months' growth, cattails and sedges had originally encroached on the cleared plot, but cordgrass densities were 3.6 times higher where competitors had been removed; by the following August (16 months after clearing and planting), the difference was 10.5 times.

Exclusion of grazers likewise had a dramatic effect on survival and vegetative reproduction of cordgrass, an effect which showed up earlier than the competition effect. Two months after planting, caged plants had twice as many shoots as uncaged plantings. However, the effect did not continue to increase, indicating that grazing is mainly a problem in the early stages of transplantation when densities are low. Once the canopy of cordgrass begins to close (or invasion of other species occurs) herbivory is less of a problem. There are at least two possible explanations for this finding: a) grazers may be less attracted to plants within a closed canopy than to those

Table 13. Initial experiments at the San Diego River marsh indicated that grazers had more effect on transplantation success than nitrogen additions or removal of competitors (pickleweed).

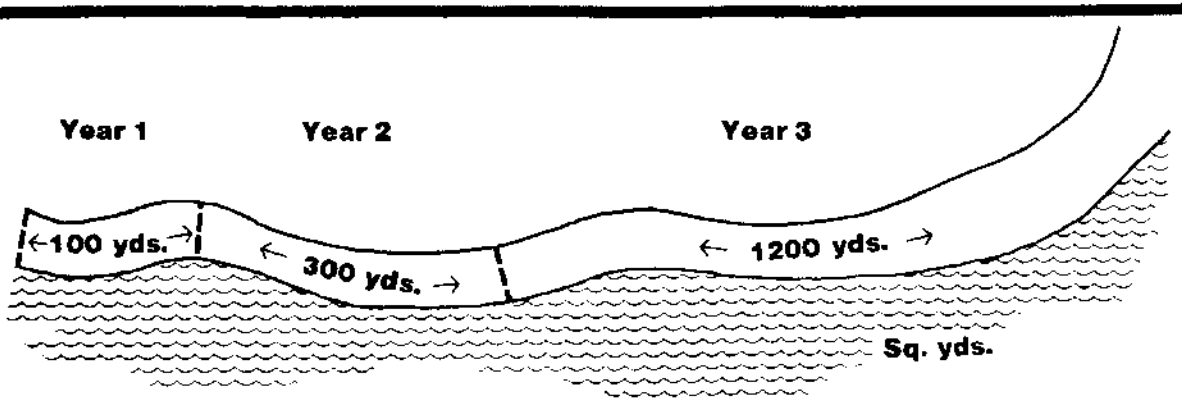
Results from first trial:

Treatment	Number of cordgrass sprigs planted on 12/10/79	Survival to: 12/28/79	Survival to: 1/15/80	Interpretation
Plus urea*	80	58	43	No effect of fertilizer
Minus urea	80	50	44	
Plus pickleweed	80	53	41	No effect of competition
Minus pickleweed	80	55	46	
Plus cages (no grazers)	80	63	59	Strong effect grazers cut survival in half
Minus cages (grazers allowed)	80	45	28	

*Approx. 90g urea was added to each m^2 (40g N m^{-2}) on 12/10/79, 12/28/79, and again on 1/15/80

Table 14. Excess fertilization and competition with cattails reduced cordgrass survival after the 1980 floods.

	Number planted 4/30/80	Survival to 5/7/80	5/20/80	6/4/80	7/3/80	12/29/80	8/18/81
Plus urea	80	80	65	64	36	–	–
Minus urea	70	70	70	108	279	329	666
Plus cattails	35	35	35	59	96	71	58
Minus cattails	35	35	35	49	183	258	608
Plus cages (no grazers)	35	35	35	74	164	139	385
Minus cages (grazers allowed)	35	35	35	34	115	190	281
Soil salinity (ppt)	2-9	2-6	2-9	4-7	2	25-26	36-41 ppt



Cumulative plantings

	Year 1	Year 2	Year 3
Yards along shore	100	400	1600
Sq. yds. of shoreline	400	1600	6400
Acres	0.08	0.33	1.26

Figure 19. Planting plan from on-site nursery to nearly a mile of planted shoreline.

surrounded by bare space and/or b) the tissues of newly planted sprigs are more attractive to grazers than those of older plants (effects of secondary plant products).

Caging out herbivores had a somewhat greater effect where the overstory vegetation had been removed than where cordgrass sprigs were "lost" in the ambient vegetation. The ratio of caged to uncaged plants was 1.3x where cattails were cleared, compared to 0.9x within the cattail canopy on 7/3/80. Because caging becomes expensive, it may be preferable to plant cordgrass within existing vegetation (where it is available), even though the sprigs will spread more slowly with a competing canopy.

The above experimental results also give a good indication of the potential that cordgrass has for vegetative expansion under various salinities. Using the values for unfertilized plantings, densities increased from 70 to 279 under mildly brackish conditions (fourfold increase in 2 months). Reproduction was slowed between July and December, probably in response to the cooler temperatures. Normally, cordgrass has its major growing period between March and September. The following year, cordgrass increased from 329 to 666 under brackish to saline conditions (only a twofold increase in an 8-month interval). Soil salinities were higher because 1981 was a drier year, and tidal water had a greater influence than runoff.

10. Extrapolating from experimental results to implementing the cordgrass establishment procedure.

Select a protected site with elevations of 3.5-4.5 feet above MLLW. Maintain soil salinities at about 20 ppt with artificial watering. Plant cordgrass at 2-yard (2-m) intervals, using sprigs.
Cage plants in aviary mesh (Fig. 11) if the site is bare of other camouflaging vegetation.

With good survival, plantings in an initially established "on-site nursery" of 100 plants (400 yd^2) should multiply to plant an additional 1200 yd^2 within one year; replanting these stems should allow ultimate plantings over a 1600 yd^2 area the following year. Thus, in three years, a total of 6000 yd^2 could have good cordgrass cover (Fig. 19).

Alternatively, use an experimental planting design.

Planting cordgrass as an experiment will take longer but will provide more information about conditions controlling transplantation success (Zedler 1983).

Year 1: Plant strips (perhaps 25 sprigs = 25 yds of shoreline) in areas of different environmental conditions (i.e., different exposure to waves, various soil salinities, etc.).

At the end of the first growing season, assess planting success, both as percentage survival of sprigs and diameter expansion of survivors.

Year 2: Based on the environmental conditions where transplantation was most successful, select areas for additional plantings, consider amending unsuitable sites to improve transplanting success, implement amendments.

Year 3: If amended sites are still unsuitable for cordgrass, consider alternative restoration measures.

ASSESSING THE PROJECT'S SUCCESS

The success of salt marsh restoration should be evaluated in two time scales: short term assessment of the new site conditions (the immediate response of the hydrological and biological features) and long-term development of the ecosystem. Success in the short-term may not assure success in the long run because marshes are dynamic systems subject to accretion and erosion. Likewise, failure in the short-term does not necessarily preclude success later on because conditions for establishment may improve as weather and other environmental factors change. For these reasons, it is essential that the detailed monitoring of initial marsh development be followed by long-term analysis of ecosystem structure and functioning.

At present there is very little information available on artificial marsh establishment at any time scale (Race and Christie 1982). Most of the experimental work has been done on dredge soil islands under the U.S. Army Corps of Engineers Dredged Material Research Program (Environmental Laboratory 1978). Of their six experimental marshes, only the Alameda Creek site in South San Francisco Bay was located in California. This was the least often monitored and least detailed study carried out in the Corps program. In southern California, various wetland restoration projects have been initiated, but none has been set up as a controlled experiment, and only one area, the western arm of Mugu Lagoon (opened to tidal flow to improve bird utilization) has been regularly monitored. There is no scientific account of any marsh restoration in the region. The experiments described in this guidebook were not intended to be whole marsh restorations but to provide methods for others to implement at a larger scale.

There are now a variety of restoration projects which are ready to utilize these recommendations. It is essential that these projects serve as whole-marsh experiments that are monitored through time and evaluated at intervals so that the results can aid the planning and implementation of newer restoration projects.

What should be monitored?

It is not enough to monitor only the planted vegetation. Salt marshes consist of hundreds of species of algae, vascular plants, invertebrates, and vertebrates (summarized in Zedler 1982a). However, the ecological complexity of the marsh makes it impossible to monitor everything. A reasonable compromise, subject to further modification, would seem to be the monitoring of those features that ecologists find to be important indicators of ecosystem function plus those features which the public views as important assets. At present, the following salt marsh characteristics fit on those lists:

- elevation
- soil salinity
- toxic compounds
- extent of unvegetated salt pans or bare ground
- plant species composition (total list present)
- plant cover and height (for each common species)
- algal cover (estimated % cover) and predominant types (diatoms, bluegreen, green, and yellowgreen algae)
- cordgrass density
- invertebrate species composition
  - especially crabs, snails, and insects
- bird use
  - especially Belding's Savannah sparrow and light-footed clapper rails
- fish utilization of tidal creeks and pools (including eggs and larvae)

Many features felt to be critical for ecological understanding of the ecosystem probably should *not* be regularly monitored in newly created marshes because they require highly destructive sampling in order to provide reliable data. Primary productivity (which requires frequent harvesting of vegetation) is such an example. Measuring animal productivity is both difficult and destructive. Therefore, the indirect measures of assessing density, cover, etc. are recommended as substitutes, at least for the short-term monitoring program.

A vertical aerial photo of the site should be obtained annually as the simplest characterization of the site. If taken in the late fall or early spring, air photos can be used to distinguish general plant communities, because the cordgrass and pickleweed will differ in color. Cordgrass becomes yellow to brown in winter; pickleweed turns red; and saltwort becomes yellow. Summer photos show most species to be green and less distinguishable.

Permanent transects should be laid out and marked for continuing measurements of the habitat at regular, easily relocated intervals from the lowest to highest elevations within the project site. At least twice a year, soil salinity should be determined. A measurement in early spring (after winter rains) will provide information on the lowest soil salinities, while a measurement in late summer (end of drought season) will provide data on the most stressful salinity conditions. Elevation should be measured once at the beginning of the marsh establishment program, and yearly or biennially thereafter. If heavy flooding occurs, additional measurements may be indicated to assess

"When we can break out of the passive mode and learn to treat the acquisition of functional information and indeed the whole management process as fundamentally experimental activities requiring active planning and judgment, then we may begin to talk about a *science* of ecological management."

Page 183 of Carl J. Walters and Ray Hilborn. 1978. Ecological optimization and adaptive management. Ann. Rev. Ecol. and Systematics 9:157-188.

erosion or accretion. Toxic compounds (hydrocarbons, Boron, heavy metals, etc.) may warrant frequent monitoring, depending on the past history of the sediments. Particle size distribution in the sediments influences soil moisture and salinity as well as invertebrate use, and this soil feature should be examined at the beginning of the project. Frequent measurement is probably not necessary unless floods or winds appear to be altering substrate texture. Organic matter content may prove useful in assessing site development, especially if soils begin with relatively low concentrations. Those features that are readily measurable (such as organic matter and pH) should be assessed in case it is later determined that the information is highly valuable – likewise, their determination should be discontinued if the data are not useful. The monitoring of artificial marshes is itself an experimental process, and new programs should benefit from past successes and failures.

RECOMMENDATIONS FOR INFORMATION STORAGE AND DISSEMINATION

Because whole-marsh restoration is still an experimental process, there needs to be established a system for filing and dispersing information on the success of each project. Who should be responsible? Who should finance it? It is easy to suggest appropriate sources, but difficult to implement a plan for depositing and disseminating information. Without regulations requiring these actions, all must be voluntary. To make the process as painless and inexpensive as possible, the following plan is proposed:

Monitoring is required of projects approved by the Coastal Commission or other public agencies.

Contractors carry out monitoring, following guidelines in the preceding section and modified to meet current Coastal Commission guidelines.

Information is assembled on standard forms, photos are taken regularly and annotated: an annual summary keyed to the forms and photos is prepared and submitted to the permitting agency.

Permitting agency staff reviews report for compliance with requirements. Returns to contractor for any necessary additions.

The Tijuana River National Estuarine Sanctuary could serve as the repository for these reports. Once its Interpretive Center is built, it could provide facilities for storage, use, and updating of such materials.

The Sanctuary Managers would then be responsible for making information available to users – either by xeroxing and distributing the requested information or by providing a place for users to examine past reports. The Manager would maintain a mailing list of users for use in advertising newly available information.

New proposals for restoration would have to include reference to previous projects in their plans, demonstrating that their plans were either improving on past experience or in accordance with current knowledge. Making sure that this was the case would be the responsibility of the Coastal Commission in consultation with Sanctuary managers.

A periodic overview of restoration should be funded at, perhaps, five-year intervals. A single contractor or research group would bring together information gathered in the previous five years, plus visit all restoration sites and compare the ecological attributes of restorations of different age. This census should probably include similar information from less disturbed marshes in conjunction with a five-year census of the estuarine sanctuary salt marsh. The ecological information to be gathered would be worked out with the sanctuary manager and concerned scientists. In preparing the synthesis of information, the monitoring data, five-year restoration census data, and sanctuary census data would be brought together to answer the following questions:

I. How similar are the artificial and less-disturbed salt marshes with regard to the list of marsh traits suggested for monitoring on page 31.

II. What variables correlate with the differences among the artificial and less disturbed salt marshes? (time since restoration, degree of tidal flushing, etc.)

III. Based on the answers to I and II, what new recommendations can be made for establishing marshes that most rapidly resemble naturally functioning ecosystems?

The synthesis report and all data would be deposited at the Sanctuary, and a summary would be distributed to us on the mailing list. The existing mailing list of attendees at the Restoration Workshop (Josselyn 1982) would serve at the start.

"Many of these experimental studies met their original goals of demonstrating the feasibility of establishing marsh vegetation on dredge spoil or eroding shores; they did not, however, answer many important questions about marsh creation. . . . To determine the true feasibility of marsh creation, rather than just vegetation establishment, a critical reevaluation of the existing information is in order."

Page 322 of Margaret Race and Donna Christie.1982. Mitigation, marsh creation and decision making in the coastal zone. Environmental Management 6:317-328.

COASTAL COMMISSION POLICY ON WETLAND RESTORATION/MITIGATION

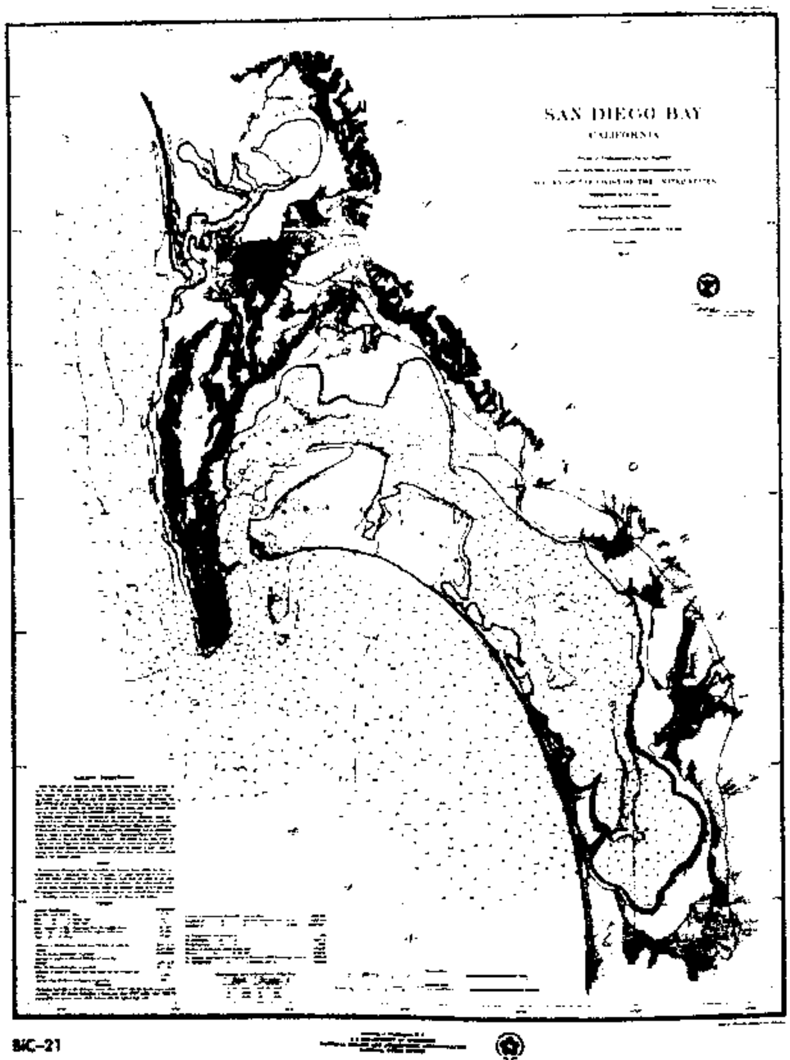
By Eric Metz, Wetlands Coordinator for the California Coastal Commission

Under the Coastal Act, wetlands are a high priority resource for conservation and enhancement. Although in very limited instances some dredging and filling of wetlands is permissible, the Commission's wetland guidelines have established that there should be *no net loss* of wetlands. According to the guidelines, "Mitigation measures should restore areas which are no longer functioning in a manner beneficial to wetland species." The Coastal Act provides the regulatory framework to require restoration in exchange for development within or adjacent to a degraded wetland, but the Commission does not receive public funds to undertake such projects on its own.

Values lost or degraded by a particular type of development should be replaced on site or in the immediate vicinity of the same marsh or estuary that will be affected by the development. The developer is responsible for the restoration costs and for dedicating the land to the public. Sometimes restoration sites are not immediately available, or difficulties are encountered in implementing the restoration program. In such cases, the developer may pay an in-lieu fee to an appropriate public agency for the purchase and restoration of an area of equivalent productive value or equivalent surface area. The California Coastal Conservancy, for example, accepts in-lieu fees for "land banking" arrangements which permit the Conservancy to implement restoration projects as sites become available.

The Commission is also acutely aware of the experimental, uncertain nature of wetland restoration. It therefore approaches mitigation efforts cautiously. An underlying philosophy adopted by the Commission is that it is better to assume that restoration projects will fall short of their expected results, than to accept the notion that the final result will be equal to or greater than the value of the destroyed area. Such a philosophy is the reason the Commission in most cases requires greater than 1:1 mitigation and requires monitoring and maintenance programs.

However, the Commission is not afraid to take some risks since, as a coastal management agency, it has a dual role. It allows and in some cases encourages reasonable and appropriate development along the coast, while assuring that coastal resources are protected. The Commission is committed to seeking innovative ways to accomplish these ends, and its guidelines provide the necessary flexibility.



Map 2. In 1859 San Diego Bay harbored a wealth of salt marshes and intertidal flats.

Exotic species are not native to the country or region where they are growing. When they become established and perpetuate themselves in their adopted land, they are said to be "naturalized." In some cases, exotic species pose particular management problems, usually as nuisances or pests (if they frequently occur where they are unwanted) or noxious weeds (if they readily invade areas where they are unwanted and resist eradication). None of the exotic halophytes has developed into such problems; most are simply curiosities – foreign plants that raise questions of how they arrived here, how long they've been present, and whether or not they compete with the native vegetation.

Salt marshes have few exotics – but they also have few native species, so even a handful of foreign species can comprise a significant fraction of the salt marsh flora. Why have so few exotic species invaded the southern California salt marsh habitat? The answer lies partly in the severe environmental conditions that species must tolerate to invade salt marsh habitats. Worldwide there are only a few plant families that have evolved mechanisms to tolerate high salinity and only a few dozen species of vascular plants that inhabit salt marshes. In addition to being able to cope with the intertidal saline habitat, species must also have good dispersal and early growth characteristics in order to establish readily. That is, they must be able to get to newly available sites and to take root and multiply rapidly. Species that produce large numbers of small, wind-borne seeds are often good terrestrial invaders, while floating seeds may be more adaptive for entrainment along the shores of bare mudflats. If we examine the exotic species in southern California's salt marshes, we find the following traits which suggest a wide variety of reasons for their ability to become naturalized (Table 15).

Once established,can exotics be eradicated? Probably not. The only attempt to eliminate an exotic plant from a southern California marsh was organized by the light-footed clapper rail Recovery Team. They were concerned that the rapidly invading mangroves at Kendall Frost Reserve would prove attractive roosts for chick predators and that the mangroves would alter the cordgrass habitat which rails prefer for nesting. A clearing crew was organized to uproot the plants, but some seedlings were inevitably missed. For even a highly visible species such as this, the thorough searching required to remove every plant would probably cause more harm than its presence. Only some form of species-specific biological control or a rare weather event that exotics could not tolerate (e.g., frost) *might* result in total eradication. More likely, the invaders, once established, will remain.

Are exotic halophytes a problem? Except for the mangrove case, little concern has been expressed over the

Table 15. Exotic halophytes in southern California salt marshes

Species	**Where from**	**Where found**	**Notes**
Avicennia marina white mangrove	New Zealand	low marsh and tidal creeks of the Kendall Frost Reserve in Mission Bay	small tree; deliberately introduced to provide material for physiological study; large seeds germinate on parent plant; drop to mud and continue growth
Cotula coronopifolia brass buttons	South Africa	common on moist soils of several plant communities; occurs in upper and middle marsh elevations	perennial; winged seeds about 2 mm long
Atriplex patula ssp. *hastata* fat hen	Eurasia	coastal salt marsh alkali sink, moist saline habitats; occurs in upper and middle marsh	annual; seed 1-2 mm
Atriplex semibaccata Australian saltbush	Australia	Saline waste places; occurs in upper marsh and transition	perennial; fleshy red fruiting bract; seeds 1.5-2 mm
Gasoul nodiflorum ice plant	probably South Africa	coastal strand, coastal sage scrub; occurs along denuded paths, upper marsh and transition	annual; seeds ~ .8 mm long
Gasoul crystallinum ice plant	"	"	annual; small seeds
Polypogon monspeliensis rabbitfoot grass	Europe	moist soils through California, including alkaline and saline soils; occurs in transition	annual grass
Parapholis incurva sickle grass	Europe	coastal salt marsh and coastal strand; occurs in transition	annual grass

Information from Munz (1974) except for white mangrove (Paul Jorgensen, pers. comm.)

invasion of salt marshes by exotic species. To date, no effect other than esthetic distaste has been identified. There may even be some value in their presence, because they indicate areas of disturbance – disking, insufficient tidal action, artificially reduced soil salinities – and because some are useful indicators of wetland habitat. On the other hand, they may be outcompeting native species, reducing the biomass of halophytes required by native fauna (e.g., insects), host-specific or even providing host plants for pest species. Powell (1978) and Nagano et al. (1981) have called for the removal of the introduced ice plant (*Carpobrotus edulis*) from southern California dune habitats, on the grounds that it is not utilized by native insects and frequently takes the place of native plants which native insects require. While no such problems have been identified for salt marsh exotics, the relationship of native and introduced species bears watching.

AN ENDANGERED PLANT: THE SALT MARSH BIRD'S BEAK

In some southern California salt marshes we find a rare and lovely plant whose flower resembles a bird's beak. Its generic name, *Cordylanthus*, refers to the flower shape – it means "club flower;" while its specific name, *maritimus*, refers to its marine-influenced habitat. The bird's beak found in southern California has been classified as a separate subspecies, *Cordylanthus maritimus* ssp. *maritimus*, and listed as an endangered species by the Federal government (Federal Register 1978). Dunn (in prep.) has reexamined the taxonomic status of the three subspecies of *C. maritimus* and finds no clear distinction, other than geographic location, among the taxa. The southern populations, however, have been greatly reduced by habitat loss and continue to be threatened by future development plans.

Since bird's beak is a part of the salt marsh community and coexists with several other species of salt marsh plants, we might ask why it and not all salt marsh species have become threatened with extinction as development encroached on the coastal wetland. Two features of the species suggest answers:

> The plant occurs in the upper part of the marsh which is close to encroaching development.
>
> The species is an annual and it must replace itself each year by setting seed – seeds which then must germinate to perpetuate the population. Most of its associates are perennials which can persist vegetatively from year to year, and even reproduce vegetatively when conditions are unsuitable for seed production.

However, neither of these explanations is sufficient to explain why bird's beak has been so dramatically reduced in population size. There are other species in the upper marsh which haven't been eliminated by encroaching development, and there are other annuals which haven't been eliminated in disturbed areas. There must be additional factors that contribute to its status as an endangered species. Dunn's (in prep.) ecological study of the population at Tijuana Estuary showed that:

> Some colonies of bird's beak disappear even when no disturbance is apparent. Later, these same colonies can become reestablished so disappearance can occur without permanent habitat modification.

These and other observations indicate that seeds continue to be viable after at least two year's dormancy. Second, it appears that germination conditions are critical to the colony's persistence.

> The phenology of bird's beak (Fig. 20) is timed as follows: germination occurs after winter rainfall; flowering begins in mid-May; fruits form in early June; and seeds appear by the middle of July.
>
> The stimulus that triggers germination appears to be lowered soil salinity brought about by the winter rains. Seeds begin to germinate when watered with fresh or slightly brackish (up to about 10 ppt) water.
>
> Seeds stored for one year maintain their viability and will germinate upon watering with low-salinity water.

These new findings provide an explanation for the observation that bird's beak colonies can fail and later reestablish: If soil salinities are unsuitable one year, seeds may remain in the habitat and germinate with the next period of low salinity. However, we still don't have a

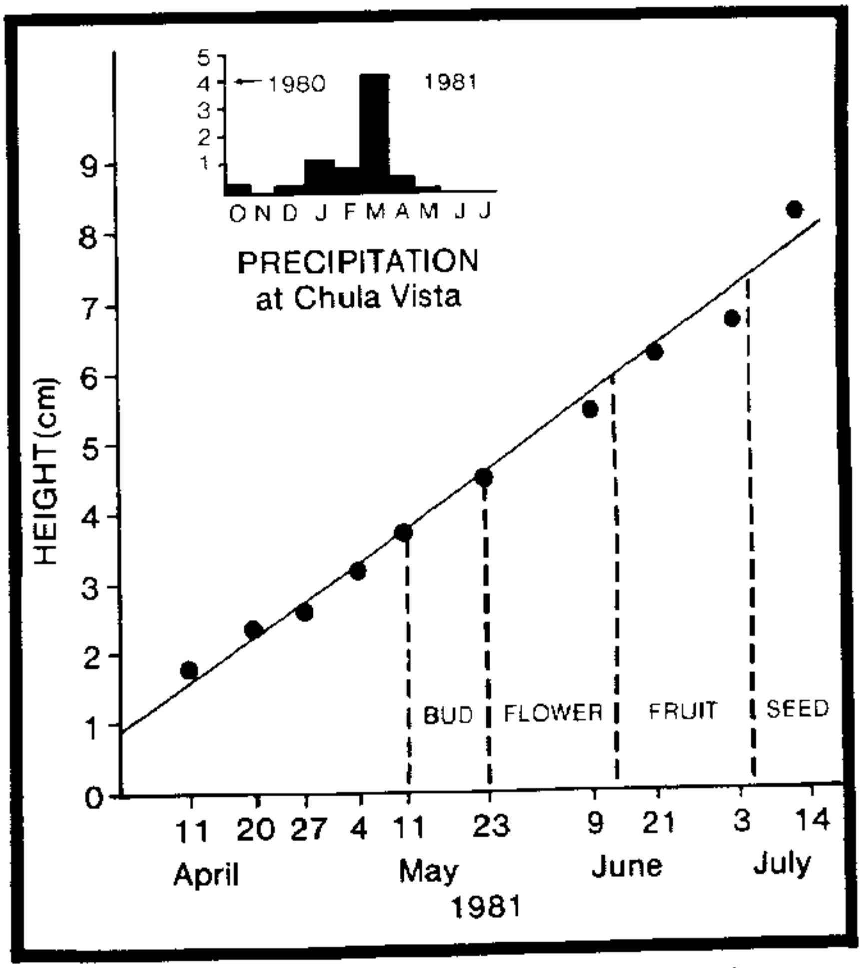


Figure 20. Height and phenology of bird's beak at the Tijuana Estuary salt marsh and rainfall at nearby Chula Vista (inset). Data points are averages of 45 plants from 3 bird's beak colonies. Redrawn from Dunn (in prep.).

complete explanation of bird's beak population decline – if local colonies can recover from years of unsuitable conditions, why has the overall trend been for population decline in several wetlands and elimination in others (e.g., Los Penasquitos Lagoon). An additional finding of Dunn at Tijuana Estuary and other southern California wetlands supplies an insight:

> Under normal conditions (relatively undisturbed marsh), bird's beak inhabits a very restricted habitat, which can be characterized by its elevational range. At Tijuana Estuary, nine measured colonies were limited to the narrow band of habitat occurring between 6-7 ft MLLW. Openings in the salt marsh canopy appeared to favor bird's beak germination and early growth.

Compared to other salt marsh species, this is an unusually narrow distribution. Bird's beak, then, is either unable to occupy a broader range of habitats or its seeds never get distributed beyond the 6-7 foot MLLW range. Dunn (in prep.) thinks that both factors act to restrict bird's beak's vertical distribution. Although he was unable to do the manipulative experiments needed to test each possibility, Dunn reasons from other observations:

> Styrofoam beads, painted to mimic the size and density of bird's beak seeds, were dispersed prior to a high tide. Most were deposited in the high-tide debris line in a narrow band which corresponded with bird's beak's distribution. The upper limit of bird's beak may coincide with tide levels at the time of seed release.
>
> A few plants found well beyond the upper limit of one colony died before maturing. Plants that happen to get dispersed beyond the usual range of bird's beak can't tolerate the conditions found there.
>
> Seed production may also be a limiting factor for the species. Both mortality of plants prior to reproductive maturity and low pollination rates of mature flowers can reduce the number of seeds produced by a colony:
>
> Dunn (in prep.) followed 45 plants through the growing season at Tijuana Estuary and only 6% lived to produce seeds. In a broader sample of plants, densities of 190/square meter were reduced to 75/square meter (40% mortality) in 23 days.
> One colony at Tijuana Estuary had a pollination rate of less than 35%, although other colonies experienced 85% pollination in the same year.

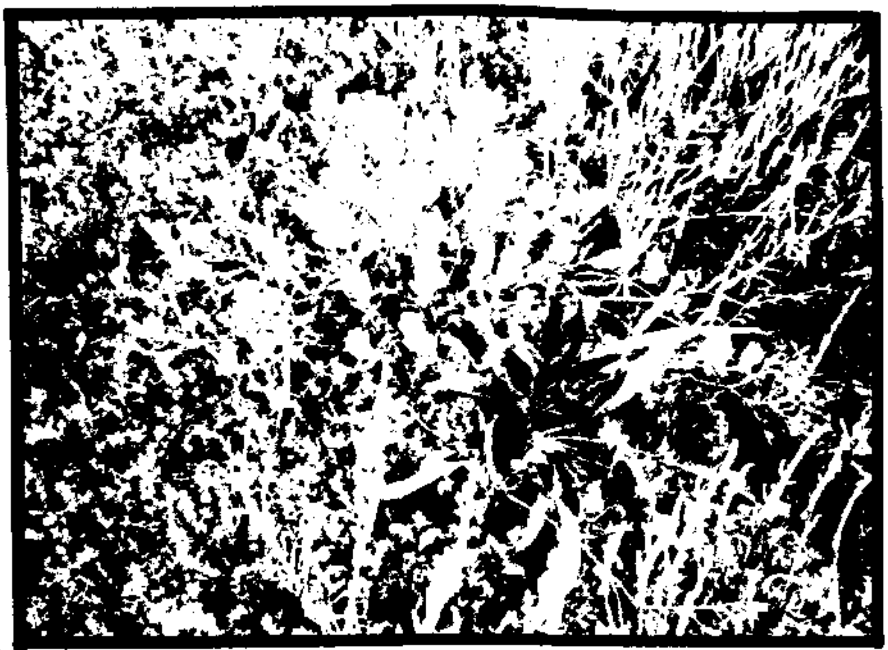


Figure 21. The salt marsh bird's beak.

Putting all of these findings together with other characteristics of the species leads to an explanation of bird's beak's susceptibility to disturbance. The narrow habitat tolerance, annual habitat, and spring growth features require that the conditions necessary for germination (low soil salinity and sufficient soil moisture) continue well into the growing season. At high elevations, the requirements of low salinity and high soil moisture will be met only if good spring rains occur. The species does form haustoria which penetrate the roots of other salt marsh species, thereby providing bird's beak with an alternative source of water (it's a hemiparasite), but haustoria formation probably requires several days to a few weeks. Prior to haustoria formation, seedling mortality can be very high. During the early growth period, tidal inundation at high elevation is a rare occurrence, and rainfall must occur to provide soil moisture. If the proper environmental conditions fail to occur during the critical establishment period, high mortality and reduced seed production can result. Man-made disturbances, such as trampling or off-road vehicle damage can further reduce colony size and chances for survival. Failure of a colony for two or more years in succession will reduce chances for reestablishment, as seed viability declines.

Can bird's beak populations be restored? It would appear that artificial establishment is a possibility, although no cases of successful restoration are on record. Certainly there should be an effort to prevent its extinction. However, we urge several precautions:

1. Manipulation of bird's beak requires a permit from the state of California and, if federal money or land is involved, a permit from the federal government is also required. Consultation with the U.S. Fish and Wildlife Service is necessary under Section 7 of the Endangered Species Act. The State Endangered Species Act requires a Memorandum of Understanding from the State Plant Ecologist. It will be necessary to obtain permission both for collecting seed and for planting it in the chosen site.

2. Minimal numbers of seeds should be obtained in June or July for an initial test planting in late March or early April. Each bird's beak plant produces about 5 capsules, and each capsule contains about 20 seeds, so that seed harvesting can be limited to just a few plants. Mature seed capsules are brownish and have begun to split open; avoid immature greenish capsules. To separate seeds from the capsule, crush capsules by hand or rub against a screen. The seeds are brown and about 2 mm in diameter.

3. Sowing of seed (obtained under permit) should be restricted to the

habitat most likely to support a healthy population. The 6-7 foot MLLW elevations of tidally flushed wetlands would provide the most natural habitat, while periods after spring rains should provide the best conditions for germination. We suggest roughing up the soil surface in patches of open canopy where other salt marsh plants are available. This will provide sufficient light for early growth as well as suitable host plants for haustoria development.

4. Experimental sowings should be marked and monitored for plant condition. The soil salinity should be monitored nearby. If soil salinity remains above 10 ppt, and seeds fail to germinate or seedlings show signs of wilting, it may be necessary to add fresh water to promote establishment.

5. Ideally, the restoration attempt should be designed as a field experiment (see Fig. 3), with replicated plots where known amounts of seed are sown and where environmental conditions (soil salinity and moisture) are monitored frequently (weekly at first). Each treatment can then be evaluated for effectiveness, and uncertainties about how to undertake future restorations will be diminished.

6. Plantings, if they succeed in producing seedlings, should be watched to maturity, and pollination rates should then be determined. If insufficient pollinators are available (as can be the case in disturbed wetlands), it may be necessary to propose corrective measures. Researchers along the Atlantic Coast are investigating the value of raising honey bees near plantings of dune vegetation! They find that seed production is enhanced in areas where pollinators are more abundant (Dietz and Krell, U. of Georgia, unpub. data).

7. A successful test planting indicates that the habitat is suitable, and some seeds from the mature test plants can be collected for wider dispersal within the site during the following spring. Because of the high potential for population expansion (approximately 100 seeds per plant), it should not be necessary to collect seeds from other wetlands after the first successful test planting. However, manual dispersal may be necessary to spread seeds beyond the initial planting. Again, marking and monitoring all test plantings will allow you to distinguish natural and artificially established colonies. Once we know whether dispersal is limiting to the spread of colonies, we can provide better advice on the most efficient means of establishing salt marsh bird's beak.

8. Finally, report findings to the U.S Fish and Wildlife Service Endangered Species Office, to the California Department of Fish and Game, to the Manager of the nearest Estuarine Sanctuary (Tijuana River Estuarine Sanctuary in southern California), and to the author for use in updating this guidebook.

Figure 22. Salt marsh bird's beak grows near the upper edge of the salt marsh, where disturbance is common. Foot paths and urban debris deposits reduce habitat for this rare plant.

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